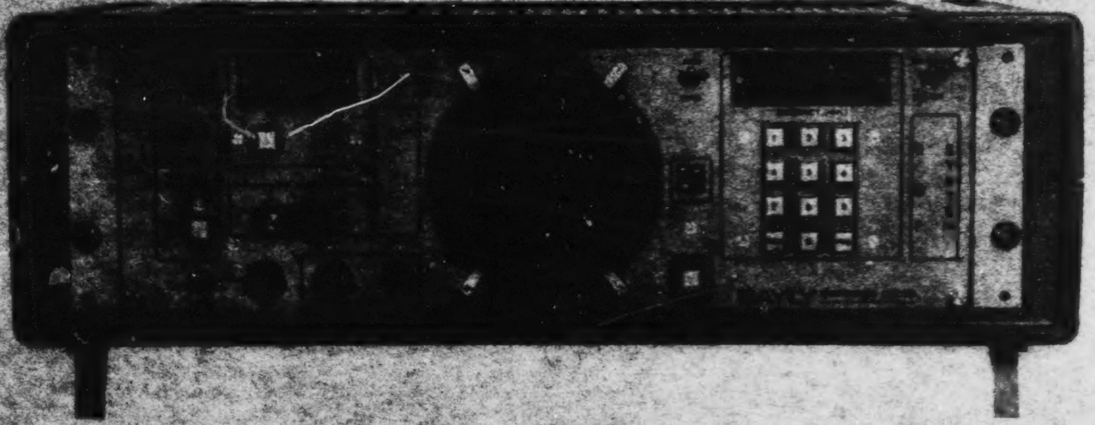
TP 5103E

FINAL REPORT

DEVELOPMENT AND TEST OF A PROTOTYPE QU[illegible]-DOPPLER MARINE VHF RADIO DIRECTION FINDER



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Amendment July 15, 1983

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BAYLY [illegible]

TP5103E

FINAL REPORT

DEVELOPMENT AND TEST OF A PROTOTYPE QUASI-DOPPLER MARINE VHF RADIO DIRECTION FINDER

by:

Bayly Engineering Limited,
167 Hunt Street, Ajax, Ontario

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Transport Canada / Transports Canada

December 1983

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

PROJECT TEAM

The project team involved in the development and testing of the Doppler radio direction finder was comprised of:

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G. Hormann

W. Ng

F. Baehr

F.J. Weilandt

R. Beck

R. Anderson

R. Menkal

and supporting staff

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MICHA AVNI

17. Abstract

A state-of-the-art Quasi-Doppler Radio Direction Finder was developed for Air Traffic Control and Marine applications. A prototype was constructed using a 16-element antenna array in the frequency range of 117.5 MHz to 136.5 MHz with the switching and active networks combined with the receiver and local control unit, all located in the ground shelter at the antenna site. A separate operator's control unit was made to link with the receiver at the antenna site, via a telephone line. The equipment was installed at the Norman Rogers Airport in Kingston, Ontario, and field tests were carried out in September through November 1983. Results of the final tests show the acceptability of the DF system for Air Traffic Control purposes. Documentation is included comprising technical notes, interim progress reports, and a technical description giving an up-to-date account of the design status of the prototype equipment.

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MICHA AVNI

17. Résumé

Un radiogoniomètre Quasi-Doppler au d'état de genie a été developpé pour les applications de contrôle du trafic aérien et maritime. Un prototype a été constru employent un rang d'antennes de 16 élements dans la bande des frequences de 117.5 MHz à 136.5 MHz, avec tous les reseaux actifs et de commutation situé dans la cabane de terre au site d'antenne. Une unitè de contrôle d'opérateur detaché a été constru pour relier avec le récepteur au site de l'antenne par une ligne teléphonique. L'équipement a été installé dans l'aérogare Norman Rogers à Kingston, Ontario et les essais de terrain ont été conduit de Septembre à Novembre 1983. Les resultats des essais finales indiquent l'acceptibilite du système radiogoniomètrique pour les desseins de contrôle du trafic aérien. Le Documentation est compris, contenant les annotations techniques, les rapports de progrés intirinaires et une description de genie qui present un compte d'état de dessin au courant de l'équipement prototype.

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FOREWORD

This report covers the development, construction and testing of the Pre-production Prototype VHF Direction Finding equipment, performed by Bayly Engineering Limited under DSS Contract File No. 12ST.T8200-1-1515 as amended July 15, 1983.

The project was a continuation of the development work described in Transport Canada Report No. TP4993E entitled Installation, Commissioning and Testing of Doppler Radio Direction Finder, dated October 1983.

This report provides comprehensive documentation on the project, which was divided into four (4) phases as follows:

PHASE I	Design
PHASE II	Prototype Construction
PHASE III	Prototype Testing
PHASE IV	Project Documentation

Each phase has been addressed in the body of the report, and supported by a number of Appendices which cover, in detail, the development work carried out between April 1983 and December 1983.

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1. INTRODUCTION

1.1 Scope

This report describes work carried out on development, construction and testing of a pre-production prototype VHF radio direction finder made by Bayly Engineering under the sponsorship of the Transportation Development Centre. The work was divided into four phases:

Phase I:	Design of an equipment, based on the Quasi-Doppler principle as originally developed for the Air Traffic Control, yet capable of meeting the requirements of applications in the Marine band.
Phase II:	Construction of a pre-production prototype, incorporating all the state-of-the-art improvements resulting from experience gained in the development and evaluation of the first operational prototype for Air Traffic Control.
Phase III:	Testing of the pre-production prototype, and the enclosed final test results showing the achieved operational performance.
Phase IV:	Project documentation, including reports, technical descriptions, and a set of schematics and parts lists relating to the final version of the pre-production prototype.

1.2 Design Objective

The specific objective of the task under Contract Amendment dated July 15, 1983 was to design a state-of-the-art prototype of a doppler radio direction finder for Air Traffic Control and Marine applications which will provide improved accuracy, greater reliability and reduced cost, as compared with units currently available, and to demonstrate the feasibility of the design in prototype hardware. The prototype was specified to operate in the Air Traffic Control VHF band, using an antenna array of 16 dipoles.

2. PHASE I - DESIGN

2.1 Report on Phase I - Design

An Interim Technical Report was prepared to complete Phase I (Design) stage of the contract. It included the following material:

i) Description of work carried out from September 1981 to April 1983.

ii) Project planning documents

iii) System specifications

vi) Description of the design concept

v) Antenna drawings

vi) Copies of progress reports numbered 1 through 10

In addition, copies of the following technical reports were included:

i) Structural analysis of the 32 element antenna.

ii) Test of frequency synthesizer for Marine Doppler.

iii) Progress Report on ATC/Marine Doppler Antenna Dipoles and associated circuits.

The Interim Technical Report of Phase I is included, for reference, in Appendix 9 of this report.

3. PHASE II - PROTOTYPE CONSTRUCTION

3.1 Basic Conditions

In accordance with Contract Amendment No. 1, the following conditions were accepted as a basis for the design and construction of a new pre-production prototype for the demonstration of design feasibility:

i) Utilization of the 16 element antenna at Kingston Airport rather than construction of a new 32 element marine antenna.

ii) Utilization of the chassis, components and circuit boards from the Kingston ATC prototype, where appropriate.

iii) Utilization of the long delivery components already procured for the marine project.

iv) Relocation of the pre-amplifiers and switching elements from the antenna tower to the equipment enclosure housing.

v) Incorporation of design changes to obtain a system accuracy (excluding site effects) of $\pm 1.5^\circ$ with a target of $\pm 1.0^\circ$ in the frequency band of 117.5 MHz to 136.5 MHz.

3.2 Planning Documents

A program was devised on the basis of the conditions of para 3.1 above and a set of planning documents was prepared and submitted to Transportation Development Centre in August 1983. A copy of this document is enclosed in Appendix 1 of this report, including the work plan, the redesign and construction schedules, and the anticipated cash flow.

3.3 System Specification

A system specification was defined, describing the performance of the new improved radio direction finding system which supersedes Annex 1 of Appendix A specification of the original contract. This new specification is attached in full in Appendix 8 of this report (Technical Description) para 1.5.

3.4 Presentation of Project Plans and Specifications

A comprehensive presentation was prepared of the project plans, the proposed improvements, specifications and work schedules for the construction of the new prototype. The presentation was made to representatives of Transport Canada at a meeting at the Bayly plant in Ajax, Ontario, in August 1983. A copy of the summary text of the presentation is enclosed in Appendix 2 of this report.

3.5 **Work Progress**

The work on design improvements, re-packaging, material procurement and construction of the prototype, was carried out from May 1983 to August 1983. The personnel on the project team were employed full time through the vacation period, and succeeded in completing the task, with only two weeks delay, which was due to late component deliveries. In-plant testing of the system was carried out in the last week of August and the new equipment was installed at the Kingston Airport test site in the first week of September 1983. A detailed account of the work progress can be seen in the copies of Monthly Progress Reports numbered 11-13 in Appendix 3 of this report.

4. PHASE III - PROTOTYPE TESTING

4.1 Plan of System Tests

A plan was prepared to test the complete radio direction finding system, as installed in the field. The tests proposed to demonstrate the system performance included:

- i) direction finding sensitivity
- ii) operational performance under a variety of signal conditions
- iii) direction finding system instrumental accuracy (excluding the site effects) and the direction finding field site accuracy
- iv) effect of polarization
- v) adjacent channel inteference
- vi) effect of two signals in the same channel
- vii) 'signal overhead' condition

4.2 Test Procedures

Copies of the test plan and test procedures were submitted to Transport Canada in August 1983, i.e. two weeks before the field demonstration. This document included a set of log sheets for filling in the results taken in the tests. A copy of the test plan is enclosed in Appendix 4 of this report.

4.3 Field Test Demonstration

A demonstration of the RDF system took place on September 7-9, 1983 in the presence of representatives of Transport Canada, Ottawa and Transportation Development Centre, Montreal. The tests were carried out in accordance with the test plan of para 4.2 above. The results were duly recorded and a test report was prepared, showing the performance of the system. A copy of the test results is enclosed in Appendix 5 of this report.

4.4 Summary of Observations and Conclusions

Results of the tests performed for the demonstration show that the equipment is in working order for all but two positions of the angle of azimuth on the corresponding angle of antenna rotation. The malfunction was identified as a fault in the bearing processor software and subsequent action was taken for its correction. Other than that, the results can be summarized as follows:

i) DF sensitivity is very good, exceeding the minimum of 5 uV/m.

ii) Effects of detuning and modulation are fully acceptable in the bandwidth of ±7.5 kHz. Change of bearing readout over a range of 72 dB of signal strength is also acceptable.

iii) Subject to repair of the above software fault, the DF system accuracy ensures bearing readings repeatable to within ±1°. An absolute error of ±3° is shown when the system is tested before calibration. Provision of built-in calibration corrections allows this error to be reduced to ±1.5° which was the objective of the new specification. After calibration, the field site errors remain within the limits of ±3°.

iv) A tilt of the transmitter antenna by ±45° may change the bearing readout from -1.5° to +2.7° depending on frequency and the angle of azimuth.

v) Interference in an adjacent channel (25 kHz away) is acceptable with the interfering signal up to 30 dB above the wanted one.

vi) With two signals in the same channel, the one stronger by 10 dB or more takes over. When the two signals are of similar strength, the bearing readout is blanked out.

vii) The 'overhead pass' indication was verified to operate at an equivalent angle of elevation of 60° ±5°.

4.5 Software Modifications

The software fault observed in the September demonstration was later identified as a condition where the reversal of the phase detector did not take place when the measured phase angle was in excess of 180°. Rather than introducing another bypass path in the already elaborate program, the design concept was changed to a much simpler one which performs effective clipping of the excess pulses, rather than going through the pre-scan sampling and reversal cycles. The new software was programmed into the existing hardware and the system performance was tested satisfactorily under extreme phase shift conditions. Phase matching of the DF receivers and of the antenna switch were checked and touched up, where required, both across the RF band and for the full range of signal levels.

4.6 Final System Performance Tests and Test Results

With the new software in place (see para 4.5 above) the radio direction finding system was re-tested for DF accuracy, repeating Test No. 3.1 and 3.2 in a manner identical to that of the September 1983 demonstration.

Results of the DF system instrumental accuracy now show the bearing errors to be within ±2°, with 94% of the readings remaining inside the ±1.5° limits. The DF field tests (transmitter rotation) show bearing results to be accurate within ±2° of the true azimuth.

A detailed final report on the software modifications, and the subsequent final test results, is attached in Appendix 6 of this report. The information provided in this appendix should be taken to replace results of Test No. 3.1 and 3.2 of the September 1983 demonstration from Appendix 5 of this report.

4.7 Conclusions

The new software in the bearing processor entirely eliminates bearing errors due to faulty operation in certain marginal conditions (noise, reflections, distortion of the antenna pattern, etc.). The final results of DF accuracy measurements show the instrumental system errors to be within ±2° without the need for calibration corrections. Similarly, the DF field site accuracy can be shown to be better than ±2° in a good DF environment, such as the Kingston Airport site.

A further improvement of the instrumental accuracy to ±1.5° or better can be achieved for the production batches by the use of more accurate test fixtures for alignment purposes.

The overall performance of the system, including the final results of DF accuracy, provides convincing proof of operational feasibility and acceptability of the equipment for the air traffic control purposes.

5. PHASE IV - PROJECT DOCUMENTATION

5.1 Design Improvements - Technical Notes

In order to arrive at the decisions of how to improve the DF system, and how to achieve the required performance, it was necessary to carry out a number of studies and reviews of the critical design areas. The results of these tasks were put in the form of brief technical notes, dated as they were completed. These notes are enclosed in Appendix 7 of this report, providing a technical background to the new design concept.

The following Technical Notes are enclosed in Appendix 7:

	Date	Title	Author
i)	20.05.82	Interaction of Antenna Elements	Z.A. Krajewski
ii)	02.06.82	Antenna for ground base Doppler DF	Z.A. Krajewski
iii)	22.06.82	Final Test on Antenna Commutator Performance	D. Pierce
iv)	16.06.83	Built-in Test Facilities	Z.A. Krajewski

5.2 Technical Description

A full description of the DF system, designed and constructed under Amendment No. 1 of the contract, is given in Appendix 8 of this report. The description includes the new system specification and the interface specifications of the functional sub-systems of the DF system.

5.3 'As Built' Circuit Diagrams, Parts Lists and Layouts

Three sets of 'as built' circuit diagrams, parts lists, and printed circuit board layouts are being submitted to Transport Canada, Transportation Development Centre under separate cover, thus completing the documentation requirements of the contract.

APPENDIX 1

PHASE II - PLANNING DOCUMENTS

AUGUST 1983

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1.0 GENERAL

1.1 Introduction

This document provides plans for the project, as defined in Appendix 'A-1', Phase II of the Amendment of the Contract. It also includes the Performance Specifications and Field Test Plans.

1.2 Comments to SOW, Phase II

4.7 The project planning documents are covered in Section 2, 3 and 4 of this document.

4.7 a), b) c) and d)

The tasks defined under these sub-paragraphs have either been implemented, or are in the process of being finalized.

4.8 Specifications are included in Section 5 of this document.

4.9 The presentation to TDC is arranged for August 18, 1983.

4.10 The electronic equipment was removed from the test site at Norman Rogers Airport and transferred to Ajax on May 18, 1983.

4.11 Work covered under this paragraph is in process.

4.12 The test plans are part of Phase III, however, it is included under Phase II, together with Performance Specifications, for convenience purposes.

4.13 Request for access to the site has been made on August 10, 1983, our telex message no. 2019.

2.0 WORK PLAN

2.1 Introduction

The project is sub-divided into tasks, based upon the equipment Family Tree (see Figure 1.1) and key personnel assigned to the project. An internal design review took place to discuss the scope of work and implement improvements and changes, as discussed between TDC and Transport Canada, and also as reflected in the Contract Amendment (Appendix 'A-1').

2.2 Task Summary

The following is a task summary of the project:

2.2.1 Electrical

- Define circuit modifications and allocate re-design tasks.
- Set the 1st prototype in operation with antenna simulator.
- Perform basic tests to confirm proposed modicications.
- Decide on division of circuits into module packages - draw up schematics.
- Assign layout tasks for PCB's of new modules.
- Produce new PCB's and assemble new modules.
- Test new modules in the system.
- Revise designs as required to achieve the performance.

2.2.2 Mechanical

- Design new enclosures.
- Design an RF shielded version of plug-in module.
- Modify front panel designs.
- Design of antenna cabling configuration.

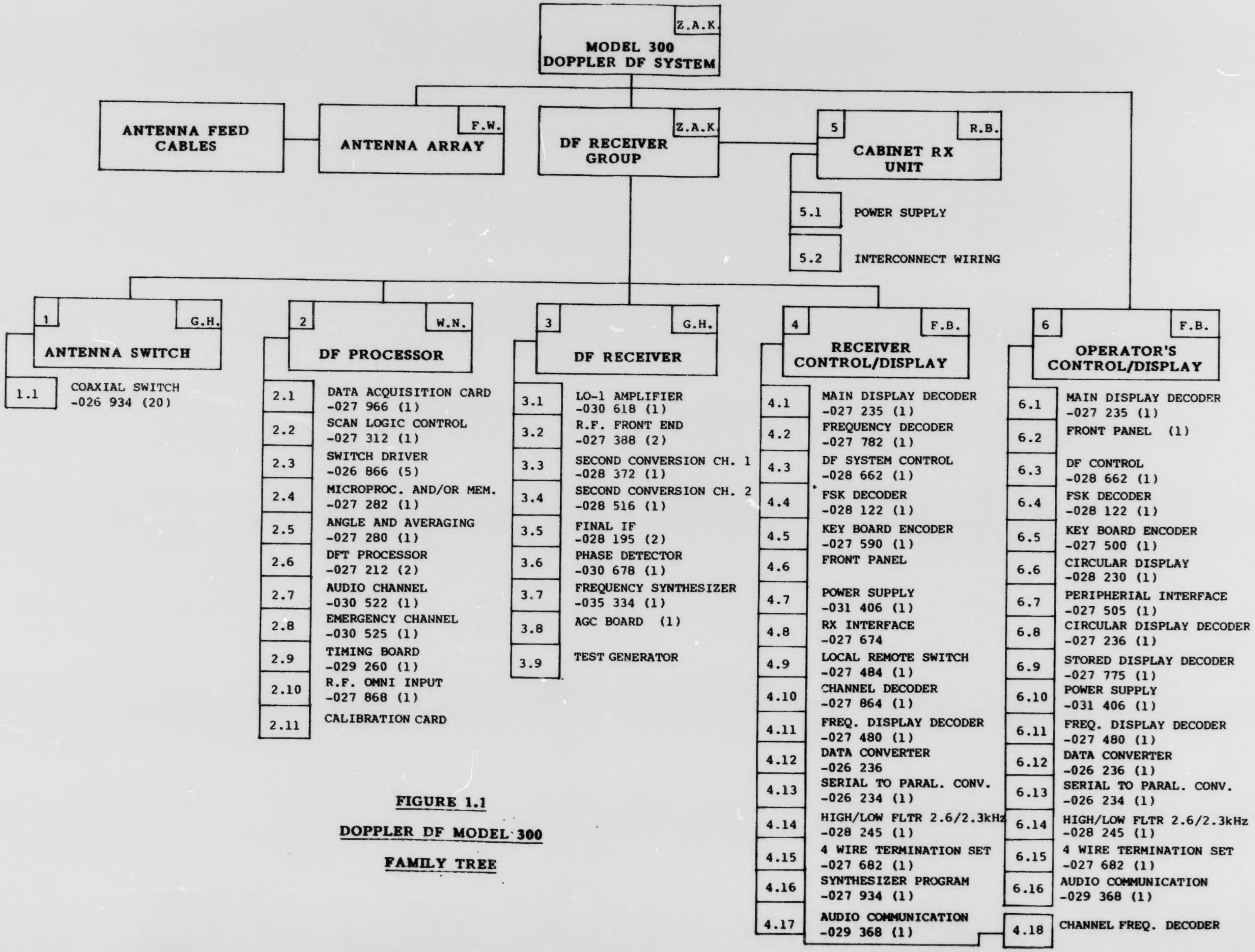

Z.A.K.
MODEL 300 DOPPLER DF SYSTEM
ANTENNA FEED CABLES
F.W.
ANTENNA ARRAY
Z.A.K.
DF RECEIVER GROUP
5
R.B.
CABINET RX UNIT
5.1 POWER SUPPLY
5.2 INTERCONNECT WIRING
1
G.H.
ANTENNA SWITCH
1.1 COAXIAL SWITCH -026 934 (20)
2
W.N.
DF PROCESSOR
2.1 DATA ACQUISITION CARD -027 966 (1)
2.2 SCAN LOGIC CONTROL -027 312 (1)
2.3 SWITCH DRIVER -026 866 (5)
2.4 MICROPROC. AND/OR MEM. -027 282 (1)
2.5 ANGLE AND AVERAGING -027 280 (1)
2.6 DFT PROCESSOR -027 212 (2)
2.7 AUDIO CHANNEL -030 522 (1)
2.8 EMERGENCY CHANNEL -030 525 (1)
2.9 TIMING BOARD -029 260 (1)
2.10 R.F. OMNI INPUT -027 868 (1)
2.11 CALIBRATION CARD
3
G.H.
DF RECEIVER
3.1 LO-1 AMPLIFIER -030 618 (1)
3.2 R.F. FRONT END -027 388 (2)
3.3 SECOND CONVERSION CH. 1 -028 372 (1)
3.4 SECOND CONVERSION CH. 2 -028 516 (1)
3.5 FINAL IF -028 195 (2)
3.6 PHASE DETECTOR -030 678 (1)
3.7 FREQUENCY SYNTHESIZER -035 334 (1)
3.8 AGC BOARD (1)
3.9 TEST GENERATOR
4
F.B.
RECEIVER CONTROL/DISPLAY
4.1 MAIN DISPLAY DECODER -027 235 (1)
4.2 FREQUENCY DECODER -027 782 (1)
4.3 DF SYSTEM CONTROL -028 662 (1)
4.4 FSK DECODER -028 122 (1)
4.5 KEY BOARD ENCODER -027 590 (1)
4.6 FRONT PANEL
4.7 POWER SUPPLY -031 406 (1)
4.8 RX INTERFACE -027 674
4.9 LOCAL REMOTE SWITCH -027 484 (1)
4.10 CHANNEL DECODER -027 864 (1)
4.11 FREQ. DISPLAY DECODER -027 480 (1)
4.12 DATA CONVERTER -026 236
4.13 SERIAL TO PARAL. CONV. -026 234 (1)
4.14 HIGH/LOW FLTR 2.6/2.3kHz -028 245 (1)
4.15 4 WIRE TERMINATION SET -027 682 (1)
4.16 SYNTHESIZER PROGRAM -027 934 (1)
4.17 AUDIO COMMUNICATION -029 368 (1)
4.18 CHANNEL FREQ. DECODER
6
F.B.
OPERATOR'S CONTROL/DISPLAY
6.1 MAIN DISPLAY DECODER -027 235 (1)
6.2 FRONT PANEL (1)
6.3 DF CONTROL -028 662 (1)
6.4 FSK DECODER -028 122 (1)
6.5 KEY BOARD ENCODER -027 500 (1)
6.6 CIRCULAR DISPLAY -028 230 (1)
6.7 PERIPHERIAL INTERFACE -027 505 (1)
6.8 CIRCULAR DISPLAY DECODER -027 236 (1)
6.9 STORED DISPLAY DECODER -027 775 (1)
6.10 POWER SUPPLY -031 406 (1)
6.11 FREQ. DISPLAY DECODER -027 480 (1)
6.12 DATA CONVERTER -026 236 (1)
6.13 SERIAL TO PARAL. CONV. -026 234 (1)
6.14 HIGH/LOW FLTR 2.6/2.3kHz -028 245 (1)
6.15 4 WIRE TERMINATION SET -027 682 (1)
6.16 AUDIO COMMUNICATION -029 368 (1)

FIGURE 1.1

DOPPLER DF MODEL 300

FAMILY TREE

2.2.3 Production

- Complete parts lists and procure missing materials.
- Review status of existing partly made items.
- Procure materials for the re-designed modules.
- Procure PCB's for modules.
- Procure cables for antenna.
- Procure mechanical components for enclosures and modules.
- Release unchanged modules to Production.
- Release modified modules to Production.
- Release enclosures and mechanical structures to Production.
- Assemble control/display prototypes.
- Assemble receiver/bearing processor prototype.

2.2.4 Electrical Tests (in the plant)

- DF receiver sub-system.
- Audio and emergency receiver.
- Bearing processor
- Receiver and operator control/display units
- Antenna switch sub-system.
- DF system test using antenna simulator.

2.2.5 Installation (Field)

- Modify antenna array to accept new cables.
- Install new cable system.
- Install DF equipment.

2.2.6 Field Test and Demonstration (test procedures similar to March 1983)

- DF system sensitivity.
- Controlled variation of test signal conditions.
- DF system accuracy (by antenna rotation).
- Field accuracy (by target rotation).
- Effect of polarization angle.
- Adjacent channel breakthrough.
- Two test signals in the same channel.
- High angle elevation (simulated test).

2.3 Project Organization

The following personnel, and responsibility, have been assigned to the project:

Z.A. Krajewski - Overall System Responsibilities
G. Hormann - Antenna Switch and DF Receiver
W. Ng - DF Processor
F. Baehr - Receiver and Operator's Control/Display
F.J. Weilandt - Antenna Feed System, including Installation and Antenna Switch Unit
R. Beck - Project Product Design
R. Anderson - Materials and Kitting of Parts for Assembly
R. Menkal - Project Management
Supporting Staff

2.4 Family Tree

The system has been sub-divided into 6 sub-systems and further broken down to module level. It also identifies an individual responsibility for each sub-system. See Figure 1.1.

3.0 SCHEDULE

3.1 Equipment Re-design and Construction

The schedule for the project has been established (see Figure 2.1). At the outset of the project, it was recognized that the schedule was rather ambitious, however, it is dictated by the availability of the site at Norman Rogers Airport, Kingston, which is available only until August 31, 1983.

3.2 Key Dates

The following are the projected dates for completion of the individual Phases of the project:

3.2.1 Phase I, II & III - August 31, 1983

3.2.2 Phase IV - October 1983

3.2.3 Field Activities - August 15-31, 1983

3.2.4 Design Review Meeting - August 18, 1983

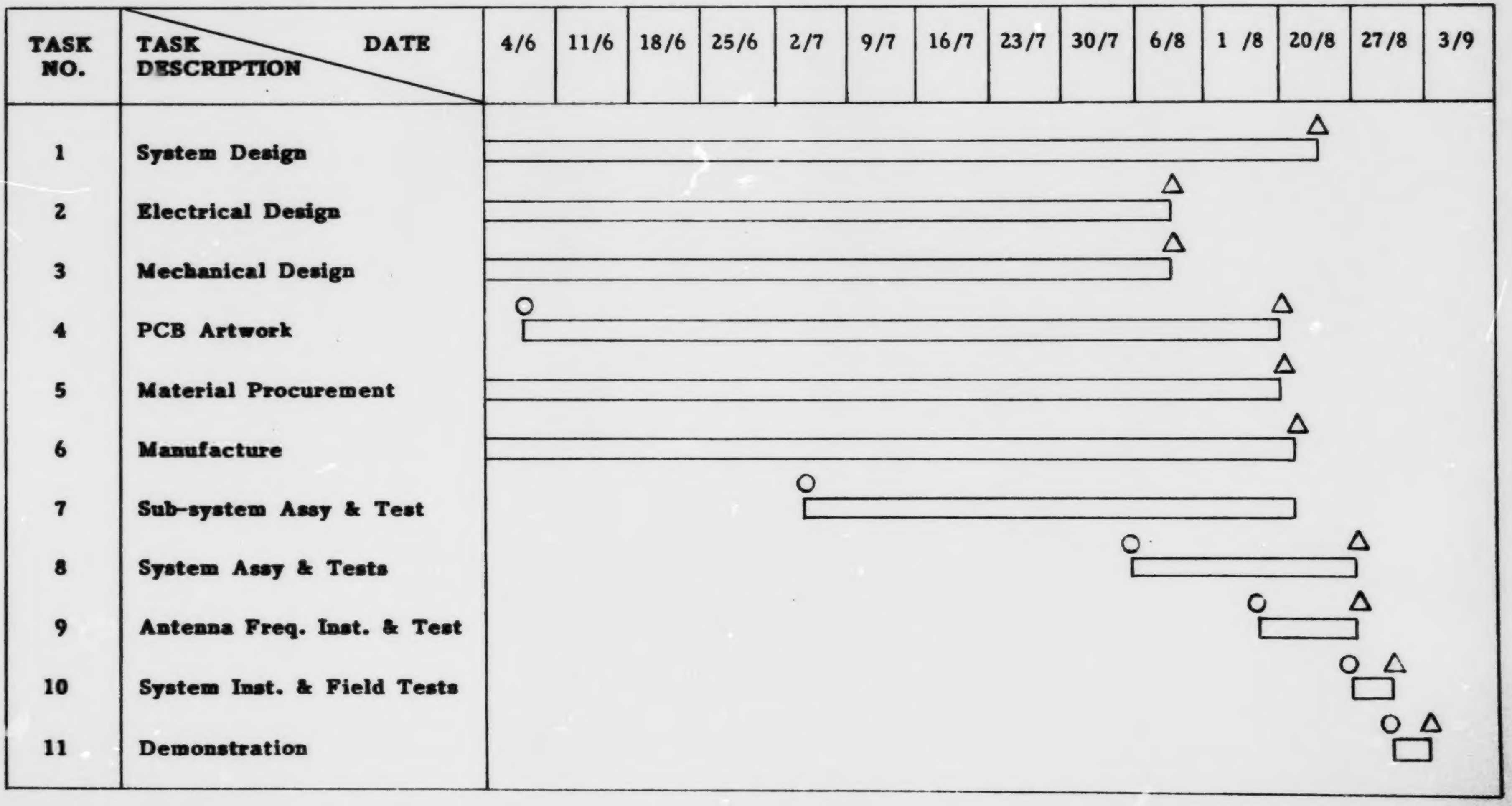
FIG. 2.1 - SCHEDULE

DOPPLER DF MODEL 300

PRE-PRODUCTION PROTOTYPE

August 13, 1983

REV. 2



4.0 CASH FLOW

The cash flow given below covers only the expenditures under the Amendment of the Contract dated July 15, 1983, for the total amount of approximately $92,000.

The work on the project was started at the beginning of May 1983, as authorized by the telex from TDC dated May 3, 1983.

May/June	-	$10,000
July	-	$34,000
August	-	$34,000
September	-	$9,000
October	-	Balance

APPENDIX 2

PRESENTATION TO TRANSPORT CANADA

PRE-PRODUCTION PROTOTYPE

AUGUST 1983

PRESENTATION TO

TRANSPORT CANADA

PRE-PRODUCTION PROTOTYPE QUASI-DOPPLER RADIO DIRECTION FINDER SYSTEM

AUGUST 18, 1983

DSS File No. 12ST.T8200-1-1515

BAYLY ENGINEERING LIMITED
a member of the AEG-TELEFUNKEN group

AGENDA

1.	INTRODUCTION	H. Schulz/R. Menkal
2.	PROJECT PLANNING	R. Menkal
3.	SYSTEM DESCRIPTION AND SPECIFICATIONS	Z.A. Krajewski
4.	PLANT TOUR	R. Menkal/Z.A. Krajewski
5.	MECHANICAL CONFIGURATION	R. Beck
6.	ANTENNA AND FEED SYSTEM	Z.A. Krajewski
7.	DF RECEIVER	G. Hormann
8.	DF PROCESSOR	W. Ng
9.	RECEIVER CONTROL/DISPLAY	F. Baehr
10.	OPERATOR'S CONTROL/DISPLAY	F. Baehr
11.	SELF TEST FACILITY	Z.A. Krajewski
12.	AUDIO AND EMERGENCY CHANNEL	G. Hormann
13.	FIELD TESTS	Z.A. Krajewski
14.	STATUS	R. Menkal

PARTICIPANTS

TRANSPORT CANADA	**M. Avni**	**Senior Development Officer, Transportation Development Centre**
	V. Caloia	**Superintendent, Enroute Aids**
	V.I. Davies	**Special Navigation and Survey Systems, Coast Guard**
BAYLY ENGINEERING LTD.	**H. Schulz**	**Executive Vice President**
	Z.A. Krajewski	**RDF System Engineering**
	G. Hormann	**Circuit Design**
	R. Beck	**Mechanical Design**
	W. Ng	**Software Development**
	F. Baehr	**Control and Display Development**
	R. Menkal	**Project Management**

PROJECT PLANNING

OBJECTIVES:

- IMPLEMENT DESIGN CHANGES TO IMPROVE PERFORMANCE, MAINTAINABILITY AND RELIABILITY OF THE SYSTEM.
- PRODUCE PRE-PRODUCTION PROTOTYPE MODEL 300.
- TEST THE SYSTEM IN PLANT AND FIELD.

HARDWARE:

- ANTENNA AND FEED SYSTEM.
- CABINET: ANTENNA SWITCH, DF RECEIVER, DF PROCESSOR, and RECEIVER AND OPERATOR'S CONTROL/DISPLAY.
- TOTAL OF 81 PCB's.

IMPLEMENTATION

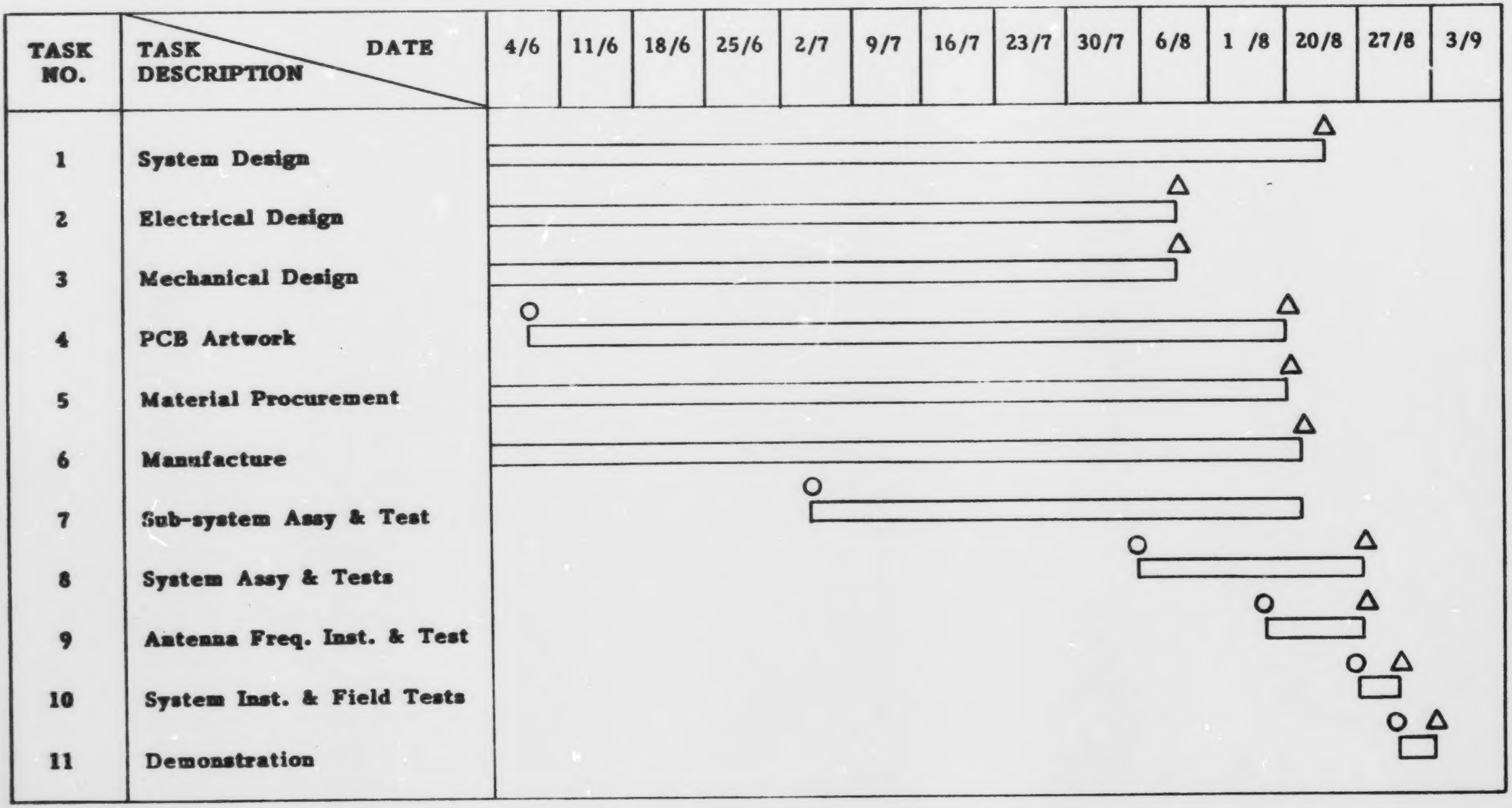
- MATERIALS
- ASSEMBLY
- TESTS: MODULES, SUB-SYSTEMS AND SYSTEM
- INSTALLATION
- FIELD TESTS

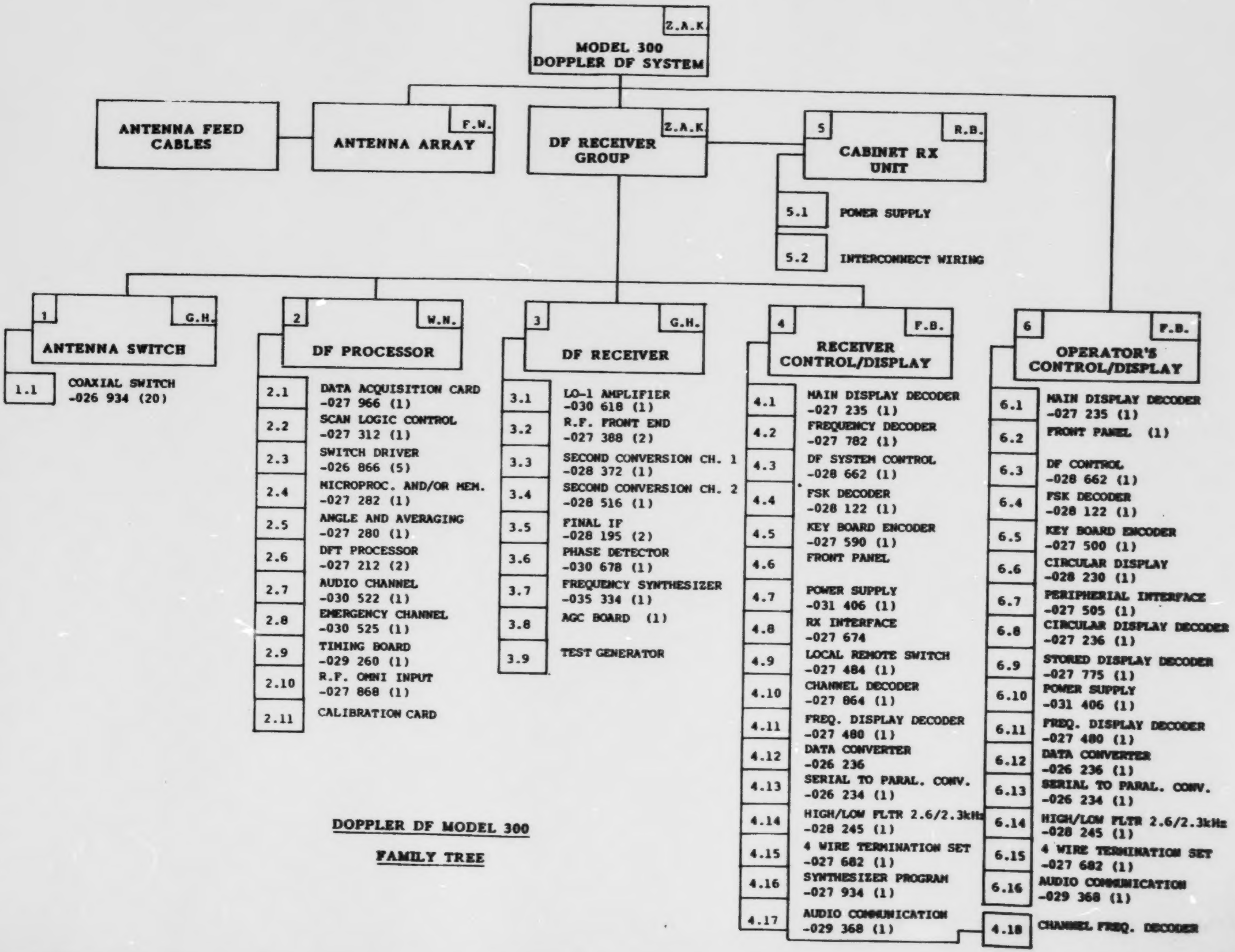
August 13, 1983

REV. 2

DOPPLER DF MODEL 300

PRE-PRODUCTION PROTOTYPE




Z.A.K.
MODEL 300
DOPPLER DF SYSTEM
ANTENNA FEED CABLES
F.W.
ANTENNA ARRAY
Z.A.K.
DF RECEIVER GROUP
5
R.B.
CABINET RX UNIT
5.1
POWER SUPPLY
5.2
INTERCONNECT WIRING
1
G.H.
ANTENNA SWITCH
1.1
COAXIAL SWITCH
-026 934 (20)
2
W.N.
DF PROCESSOR
2.1
DATA ACQUISITION CARD
-027 966 (1)
2.2
SCAN LOGIC CONTROL
-027 312 (1)
2.3
SWITCH DRIVER
-026 866 (5)
2.4
MICROPROC. AND/OR MEM.
-027 282 (1)
2.5
ANGLE AND AVERAGING
-027 280 (1)
2.6
DFT PROCESSOR
-027 212 (2)
2.7
AUDIO CHANNEL
-030 522 (1)
2.8
EMERGENCY CHANNEL
-030 525 (1)
2.9
TIMING BOARD
-029 260 (1)
2.10
R.F. OMNI INPUT
-027 868 (1)
2.11
CALIBRATION CARD
3
G.H.
DF RECEIVER
3.1
LO-1 AMPLIFIER
-030 618 (1)
3.2
R.F. FRONT END
-027 388 (2)
3.3
SECOND CONVERSION CH. 1
-028 372 (1)
3.4
SECOND CONVERSION CH. 2
-028 516 (1)
3.5
FINAL IF
-028 195 (2)
3.6
PHASE DETECTOR
-030 678 (1)
3.7
FREQUENCY SYNTHESIZER
-035 334 (1)
3.8
AGC BOARD (1)
3.9
TEST GENERATOR
4
F.B.
RECEIVER CONTROL/DISPLAY
4.1
MAIN DISPLAY DECODER
-027 235 (1)
4.2
FREQUENCY DECODER
-027 782 (1)
4.3
DF SYSTEM CONTROL
-028 662 (1)
4.4
FSK DECODER
-028 122 (1)
4.5
KEY BOARD ENCODER
-027 590 (1)
4.6
FRONT PANEL
4.7
POWER SUPPLY
-031 406 (1)
4.8
RX INTERFACE
-027 674
4.9
LOCAL REMOTE SWITCH
-027 484 (1)
4.10
CHANNEL DECODER
-027 864 (1)
4.11
FREQ. DISPLAY DECODER
-027 480 (1)
4.12
DATA CONVERTER
-026 236
4.13
SERIAL TO PARAL. CONV.
-026 234 (1)
4.14
HIGH/LOW FLTR 2.6/2.3kHz
-028 245 (1)
4.15
4 WIRE TERMINATION SET
-027 682 (1)
4.16
SYNTHESIZER PROGRAM
-027 934 (1)
4.17
AUDIO COMMUNICATION
-029 368 (1)
4.18
CHANNEL FREQ. DECODER
6
F.B.
OPERATOR'S CONTROL/DISPLAY
6.1
MAIN DISPLAY DECODER
-027 235 (1)
6.2
FRONT PANEL (1)
6.3
DF CONTROL
-028 662 (1)
6.4
FSK DECODER
-028 122 (1)
6.5
KEY BOARD ENCODER
-027 500 (1)
6.6
CIRCULAR DISPLAY
-028 230 (1)
6.7
PERIPHERIAL INTERFACE
-027 505 (1)
6.8
CIRCULAR DISPLAY DECODER
-027 236 (1)
6.9
STORED DISPLAY DECODER
-027 775 (1)
6.10
POWER SUPPLY
-031 406 (1)
6.11
FREQ. DISPLAY DECODER
-027 480 (1)
6.12
DATA CONVERTER
-026 236 (1)
6.13
SERIAL TO PARAL. CONV.
-026 234 (1)
6.14
HIGH/LOW FLTR 2.6/2.3kHz
-028 245 (1)
6.15
4 WIRE TERMINATION SET
-027 682 (1)
6.16
AUDIO COMMUNICATION
-029 368 (1)

DOPPLER DF MODEL 300

FAMILY TREE

SYSTEM CONFIGURATION

- ANTENNA ARRAY OF 16 DIPOLES, AND ONE OMNI-DIRECTIONAL, MONOPOLE, WITH DOWN-FEED CABLES
- DF RECEIVER AND DF DATA PROCESSOR WITH LOCAL CONTROL/DISPLAY UNIT
- OPERATOR'S CONTROL/DISPLAY UNIT

DESIGN HIGHLIGHTS

- QUASI-DOPPLER PRINCIPLE, PHASE DIFFERENCE SAMPLING
- 'SOFT SWITCHING' OF DIPOLES (LOW IM)
- DIGITAL BEARING PROCESSOR
- RECEIVER ERROR ELIMINATION
- CIRCULAR AZIMUTH DISPLAY
- DIRECT FREQUENCY DIALING IN ADDITION TO 11 PRESET CHANNELS
- REMOTE CONTROL AND MONITORING OVER STANDARD TELEPHONE LINES
- BUILT-IN SYSTEM TEST

2nd PROTOTYPE FOR ATC

SUMMARY OF IMPROVEMENTS

ELECTRICAL

- Receiver modules re-packaged and circuits modified to provide better gain and AGC distribution in order to improve handling of high level signals.
- The 2nd Local Oscillator frequency changed from 32.2 MHz to 27.8 MHz to remove its harmonics from the operating band.
- Phase detector linearity improved by re-designing a low-pass filter.
- Circuit added for elimination of phase detector ambiguities.
- Integration constant selected automatically.
- Preset channel frequency indication now displayed on the LED frequency readout.
- Complete re-design of the audio and emergency receivers, based on a frequency plan which allows the use of standard smaller, and less expensive, components. This sub-system is now packaged in three standard modules.

2nd PROTOTYPE FOR ATC

SUMMARY OF IMPROVEMENTS (Cont'd)

MECHANICAL

- Transfer of Antenna Unit from top of the mast to the shelter, and design of a new antenna feed system (17 semi-rigid coax cables with N-type connectors).
- Re-packaging of all receiver and antenna unit modules into a single cabinet (24" high, 21" wide and 18" deep).
- Re-design of receiver and operator's control/display front panels to reduce congestion.
- Improvement of ventilation, no forced air cooling required.

MAINTAINABILITY

- New concept designed of system self-test facility. This is based on injecting an RF test signal into the Omni antenna and analyzing consecutive outputs from the 16 dipoles.
- Addition of front panel test points for troubleshooting and alignment purposes.
- Improvement of accessibility for module replacement.

PERFORMANCE CHARACTERISTICS

DF SYSTEM

1.	Frequency Range	:	117.5 - 136.5 MHz
2.	Principle of Operation	:	Large aperture Quasi-Doppler with differential sampling of 16 antenna elements.
3.	Equipment Accuracy	:	±1.5° (target ±1.0°) measured with antenna simulator.
4.	System Accuracy (Installed)	:	±3° with 16 element antenna.
5.	Polarization Error	:	2° max. with 45° tilt of Tx antenna.
6.	Sensitivity (vertical polarization)	:	≤5 µV/m for ±1°of noise flicker.
7.	Group Delay Error	:	Cancelled out by digital processing.
8.	DF Receiver Phase Match Error	:	Cancelled out by Bearing Processor.
9.	Mode Operation	:	Continous, unattended.
10.	Number of Frequency Channels	:	Emergency Channel plus 10 switch-selected - each channel frequency programmable within the equipment and full range of 720 channels, operator selectable by push-button dialing.
11.	Channel Spacing	:	25 kHz
12.	Acceptance Bandwidth	:	±7.5 kHz

PERFORMANCE CHARACTERISTICS (Cont'd)

DF SYSTEM (Cont'd)

13. **Adjacent Channel Breakthrough** : $\leq$1° error with adjacent channel signal up to 30 dB above wanted signal but not exceeding 30 mV/m.

14. **Bearing Indication** : 4 digits with LED numerals blanking out at no signal unless connected to store: display at both local and remote units. Analog display circle of LED's in 5° steps at Operator's Panel only.

15. **Response Time** : 0.2 sec. to 0.8 sec., depending on the signal strength.

16. **Bearing Readout Update** : Equal to integration constant.

17. **Valid Display Indicator** : Inaccurate bearings fluctuating by more than ±10° are blanked out.

18. **Operator Panel Controls** : Power On/Off; Dimmer (bearing and channel display only); Lamp test; Channel select (illum. push-button); QDM/QDR; Store On/Off with indicator; Remote control indicator; System alarm indicator; Signal overhead indicator; Frequency select mode and rest; Auto/man. switch; Alarm LED.

19. **Receiver Panel Controls** : As above, except no store On/Off and indicator; Squelch On/Off; Synthesizer phase lock indicator.

20. **Auxiliary Data Output** : At both local and remote units, TTL compatible parallel data bit format.

PERFORMANCE CHARACTERISTICS (Cont'd)

DF SYSTEM (Cont'd)

21.	Auxiliary Channel Select	At the remote unit for control from another site.
22.	Squelch Threshold	Fully adjustable from front panel of remote.
23.	Service Telephone	Jacks provided for 2-way communication between remote and local units (audio channel disabled).
24.	Aircraft Warning Light	Integrated with antenna structure (may be left out if not required).

AUDIO MONITORING

25.	Omni-directional Antenna	Centre of the array.
26.	Frequency	Automatically tuned with the DF system.
27.	Type of Detector	AM
28.	Output	0.5W loudspeakers on both remote and local units.
29.	Auxiliary Output	50 mV at 600 Ohms on the local unit.
30.	Squelch	Provided on Remote Unit.
31.	AGC	Provided on Remote Unit.
32.	Volume Control	Individual with each loudspeaker.

PERFORMANCE CHARACTERISTICS (Cont'd)

EMERGENCY RECEIVER

33. Antenna : Common with audio monitoring provided with separator filter.

34. Tuning : Set at 121.5 MHz

35. AGC : Pre-set

36. Detector : Carrier presence above threshold pre-set at the Remote Unit.

DOPPLER DF FOR MARINE APPLICATION

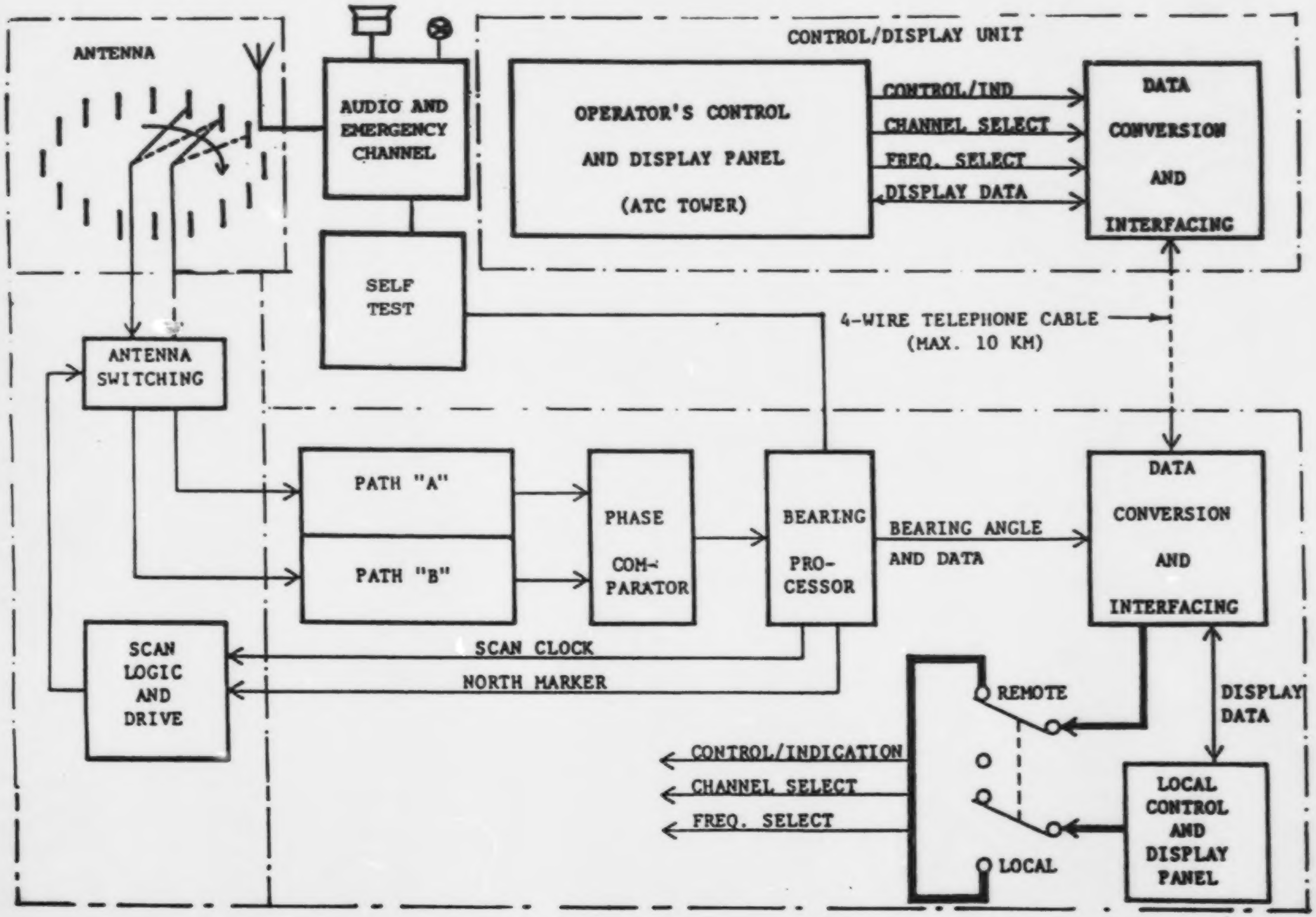
SUMMARY OF SPEC. FEATURES DIFFERENT FROM THE ATC SYSTEM

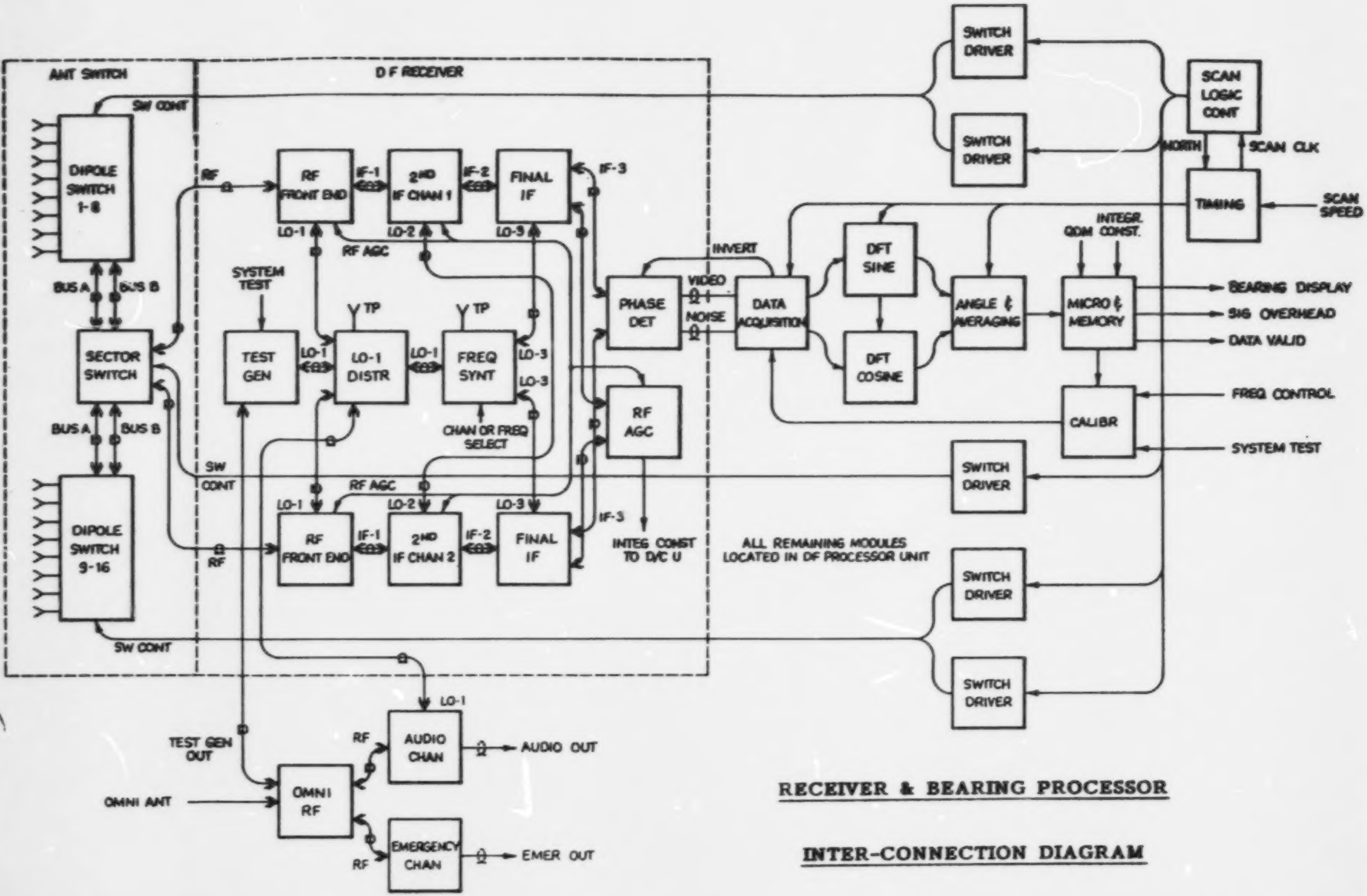
- Frequency Range : 156 MHz to 164 MHz
- Antenna Array : 32 Dipoles
- Equipment Accuracy : ±0.5° (target ±0.3°)
- Antenna Scan Frequency : 50 Hz approx. (switchable)
- Number of Freq. Channels : 10 + 1 preset channels (programmable), plus 320 channels selected by direct frequency dialing
- Response Time : 0.2 sec. to 2.0 sec. selected automatically according to signal strength

CHANGES REQUIRED TO HARDWARE OR SOFTWARE

- Antenna Array (with 32 dipoles tuned to the Marine Band)
- RF Filters (RF front end, Omni and LO-1 amplifier modules)
- Frequency synthesizer module
- Frequency and channel programming
- Antenna switching program (32 position scan) and switch assembly
- Bearing analysis software (32 samples)
- Scan timing adjustment

SYSTEM BLOCK DIAGRAM


ANTENNA
AUDIO AND EMERGENCY CHANNEL
CONTROL/DISPLAY UNIT
OPERATOR'S CONTROL AND DISPLAY PANEL (ATC TOWER)
CONTROL/IND
CHANNEL SELECT
FREQ. SELECT
DISPLAY DATA
DATA CONVERSION AND INTERFACING
SELF TEST
4-WIRE TELEPHONE CABLE (MAX. 10 KM)
ANTENNA SWITCHING
PATH "A"
PATH "B"
PHASE COM-PARATOR
BEARING PRO-CESSOR
BEARING ANGLE AND DATA
DATA CONVERSION AND INTERFACING
SCAN LOGIC AND DRIVE
SCAN CLOCK
NORTH MARKER
REMOTE
LOCAL
DISPLAY DATA
CONTROL/INDICATION
CHANNEL SELECT
FREQ. SELECT
LOCAL CONTROL AND DISPLAY PANEL


ANT SWITCH
D F RECEIVER
DIPOLE SWITCH 1-8
SW CONT
BUS A
BUS B
SECTOR SWITCH
BUS A
BUS B
DIPOLE SWITCH 9-16
SW CONT
SW CONT
RF
RF
RF FRONT END
IF-1
2ND IF CHAN 1
IF-2
FINAL IF
IF-3
LO-1
RF AGC
LO-2
LO-3
SYSTEM TEST
TEST GEN
LO-1
LO-1 DISTR
TP
LO-1
FREQ SYNT
TP
LO-3
LO-3
CHAN OR FREQ SELECT
RF AGC
LO-1
LO-2
LO-3
RF FRONT END
IF-1
2ND IF CHAN 2
IF-2
FINAL IF
IF-3
PHASE DET
RF AGC
INTEG CONST TO D/C U
INVERT
VIDEO
NOISE
DATA ACQUISITION
DFT SINE
DFT COSINE
ANGLE & AVERAGING
QDM
INTEGR. CONST.
MICRO & MEMORY
BEARING DISPLAY
SIG OVERHEAD
DATA VALID
CALIBR
FREQ CONTROL
SYSTEM TEST
SWITCH DRIVER
SWITCH DRIVER
SWITCH DRIVER
SWITCH DRIVER
SWITCH DRIVER
SCAN LOGIC CONT
NORTH
SCAN CLK
TIMING
SCAN SPEED
ALL REMAINING MODULES LOCATED IN DF PROCESSOR UNIT
LO-1
TEST GEN OUT
OMNI ANT
OMNI RF
RF
AUDIO CHAN
AUDIO OUT
RF
EMERGENCY CHAN
EMER OUT

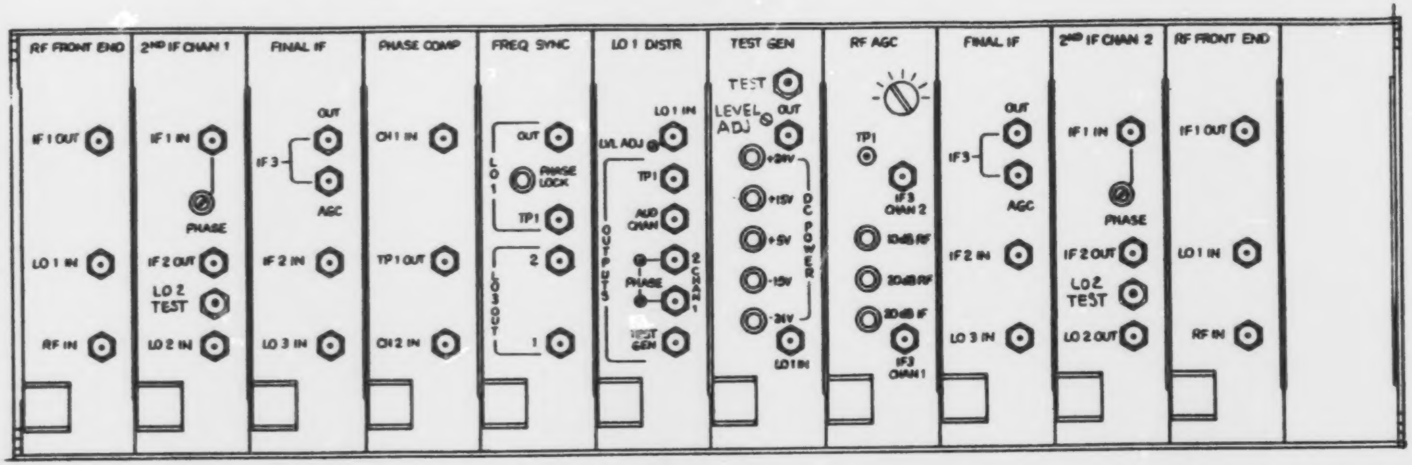
RECEIVER & BEARING PROCESSOR

INTER-CONNECTION DIAGRAM

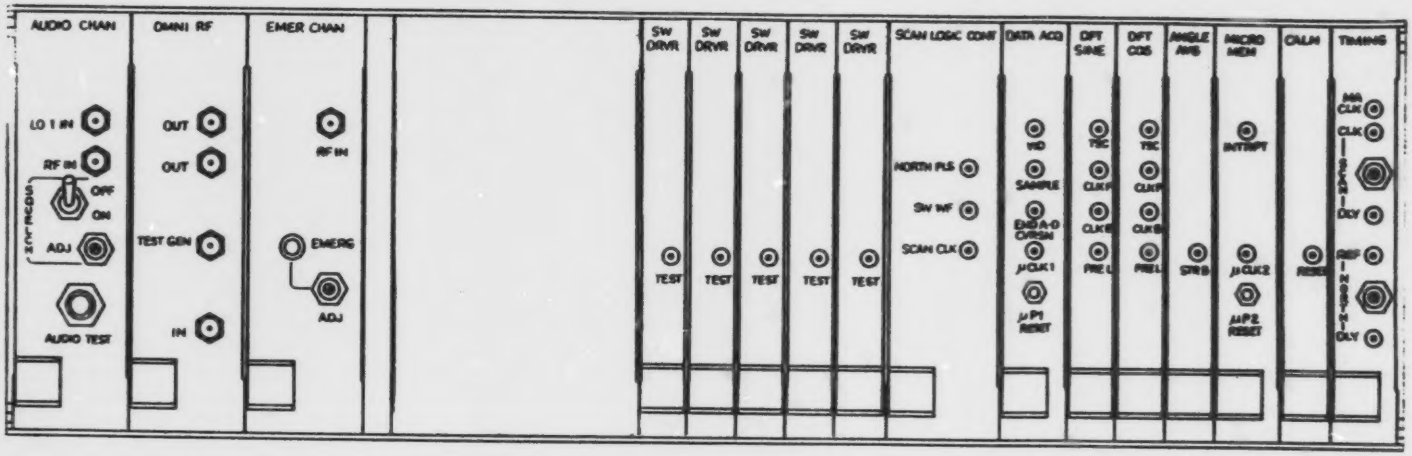
FUNCTIONAL SUB-SYSTEMS

1. ANTENNA ARRAY WITH FEED CABLES AND DIPOLE COMMUTATION
2. TWIN-CHANNEL DF RECEIVER
3. BEARING PROCESSOR
4. DISPLAY AND CONTROL
5. DATA AND VOICE TRANSMISSION
6. OMNI-DIRECTIONAL MONITORING RECEIVERS (AUDIO & EMERGENCY)
7. SYSTEM SELF-TEST

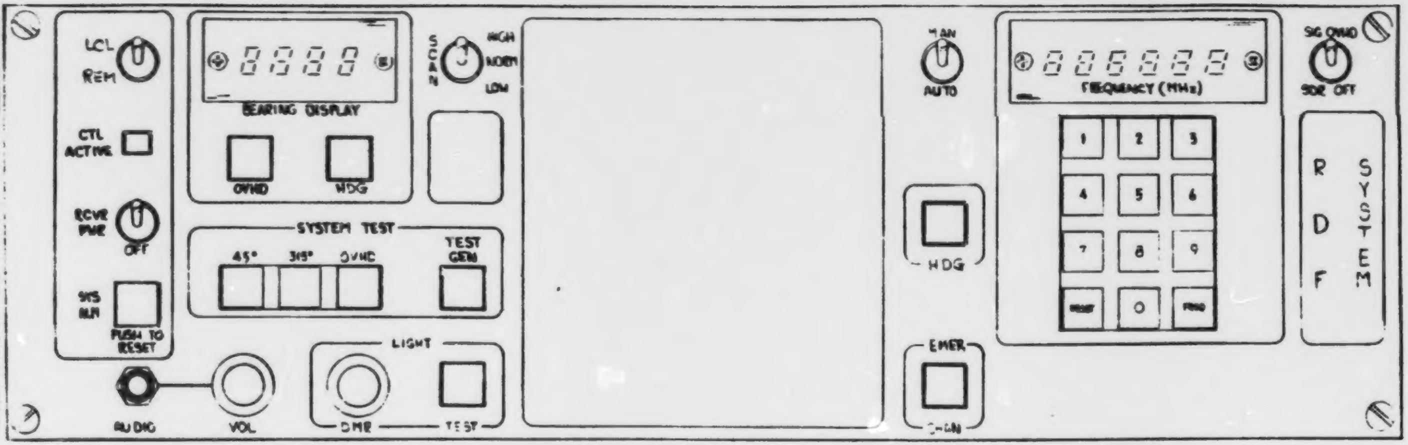
DF RECEIVER


RF FRONT END
IF 1 OUT
LO 1 IN
RF IN
2ND IF CHAN 1
IF 1 IN
PHASE
IF 2 OUT
LO 2 TEST
LO 2 IN
FINAL IF
OUT
IF 3
AGC
IF 2 IN
LO 3 IN
PHASE COMP
CH 1 IN
TP 1 OUT
CH 2 IN
FREQ SYNC
OUT
LO 1
PHASE LOCK
TP1
2
LO 3 OUT
1
LO 1 DISTR
LO 1 IN
LVL ADJ
TP1
AUD CHAN
OUTPUTS
2 CHAN 1
PHASE
TEST GEN
TEST GEN
TEST
LEVEL ADJ
OUT
+24V
+15V
+5V
-15V
-24V
DC POWER
LO 1 IN
RF AGC
TP1
IF3 CHAN 2
10dB RF
20dB RF
20dB IF
IF3 CHAN 1
FINAL IF
OUT
IF3
AGC
IF 2 IN
LO 3 IN
2ND IF CHAN 2
IF 1 IN
PHASE
IF 2 OUT
LO2 TEST
LO 2 OUT
RF FRONT END
IF 1 OUT
LO 1 IN
RF IN

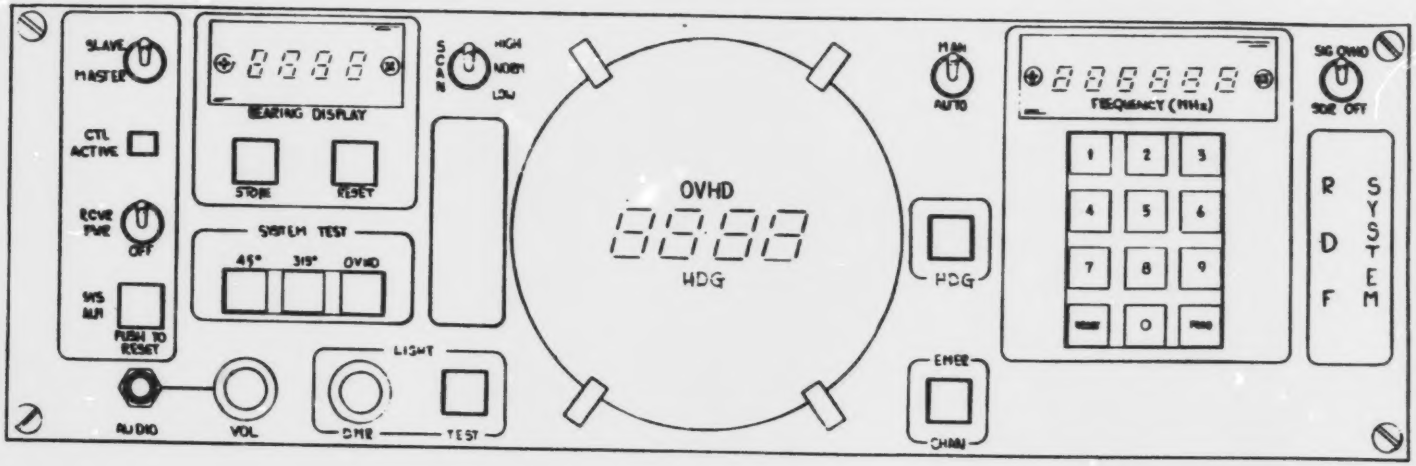
DF PROCESSOR


AUDIO CHAN
LO 1 IN
RF IN
OFF
ON
ADJ
AUDIO TEST
OMNI RF
OUT
OUT
TEST GEN
IN
EMER CHAN
RF IN
EMERG
ADJ
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SCAN LOGIC CONT
NORTH PLS
SW INF
SCAN CLK
DATA ACQ
VID
SAMPLE
END A-D CVRSN
µCLK1
µP1 RESET
DFT SINE
TRIC
CLK F
CLK B
PRE L
DFT COS
TRIC
CLK F
CLK B
PRE L
ANGLE AVG
STRB
MICRO MEM
INTRPT
µCLK2
µP2 RESET
CALM
RESET
TIMING
MA CLK
CLK
SCAN
DLY
REF
NORTH
DLY

RECEIVER CONTROL/DISPLAY


LCL
REM
CTL ACTIVE
RCVR PWR
OFF
SYS RUN
PUSH TO RESET
AUDIO
VOL
BEARING DISPLAY
OVHD
HDG
SCAN
HIGH
NORM
LOW
SYSTEM TEST
45°
315°
OVHD
TEST GEN
LIGHT
DMR
TEST
MAN
AUTO
HDG
EMER
CHAN
FREQUENCY (MHz)
1
2
3
4
5
6
7
8
9
0
SG OVHD
SDR OFF
RDF SYSTEM

OPERATOR'S CONTROL/DISPLAY


SLAVE
MASTER
CTL ACTIVE
RCVR PWR
OFF
SYS ALM
PUSH TO RESET
AUDIO
VOL
BEARING DISPLAY
STORE
RESET
SYSTEM TEST
45°
315°
OVHD
LIGHT
DMR
TEST
SCAN
HIGH
NORM
LOW
OVHD
HDG
MAN
AUTO
HDG
EMER
CHAN
FREQUENCY (MHz)
1
2
3
4
5
6
7
8
9
0
SIG CMND
SDR OFF
RDF
SYSTEM

ANTENNA ARRAY AND COMMUTATION

SUB-SYSTEM ELEMENT:

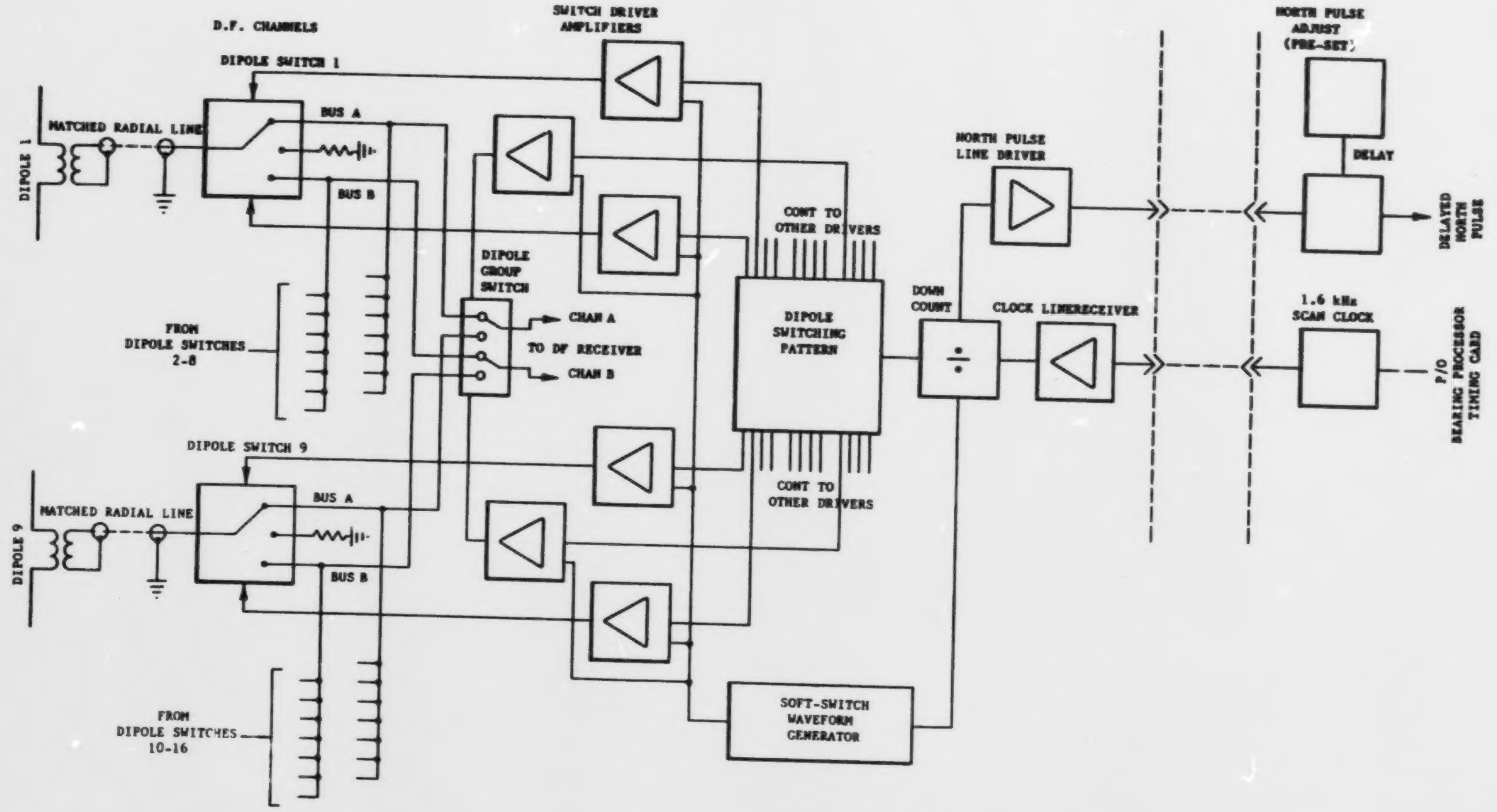
- Circular array of 16 vertical dipoles
- Omni-directional monitoring antenna in the centre of the array
- Low-loss, down-feed cables
- PIN-diode switch assembly
- Set of antenna switch drivers
- Scan logic control module

DESIGN CONCEPT:

- Scanning of dipole pairs
- Commutation program
- 'Soft switching' technique

ADVANTAGES OF DESIGN REVISION:

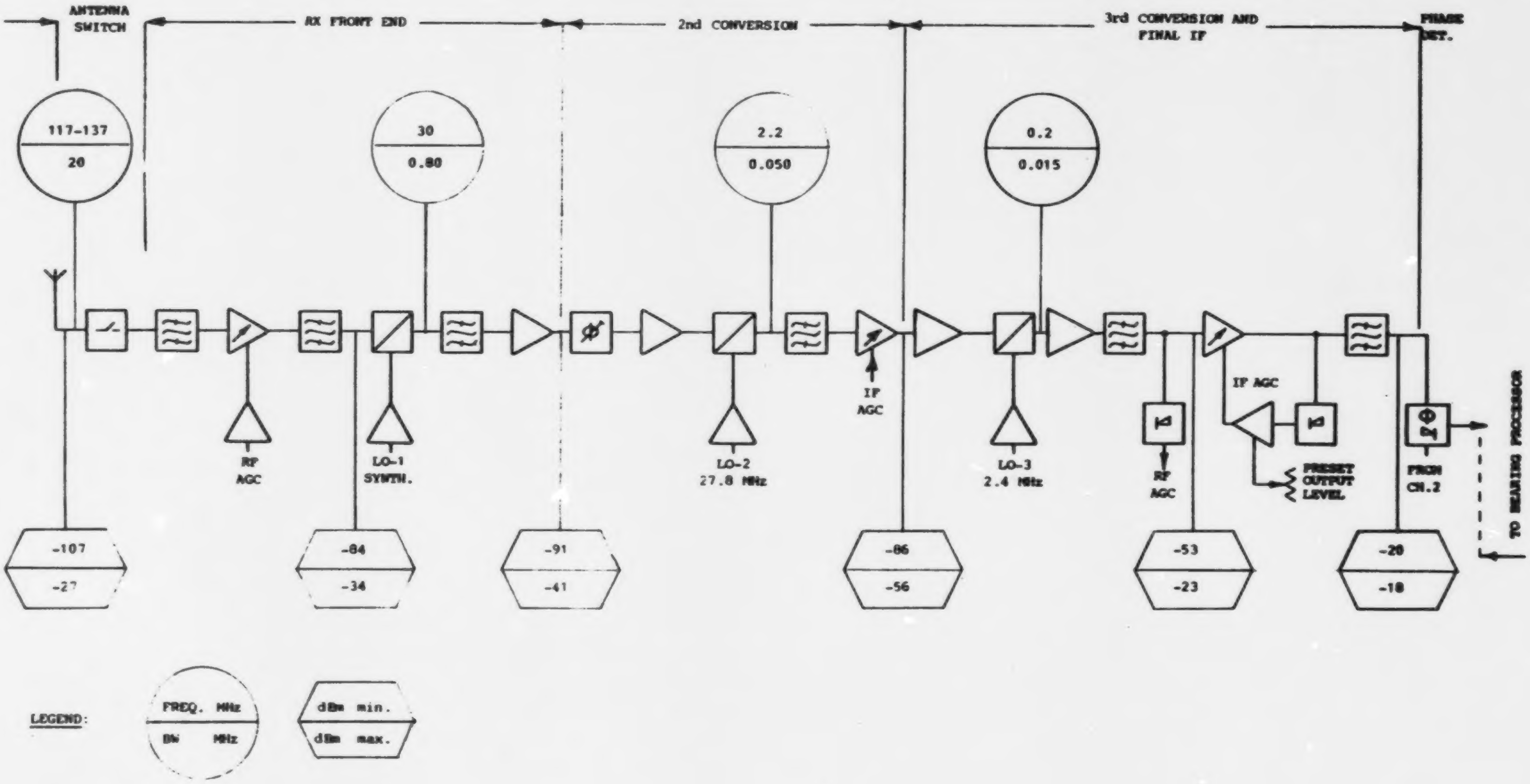
- Array symmetry
- Accessibility
- Environmental conditions


D.F. CHANNELS
DIPOLE SWITCH 1
DIPOLE 1
MATCHED RADIAL LINE
BUS A
BUS B
SWITCH DRIVER AMPLIFIERS
DIPOLE GROUP SWITCH
CHAN A
TO DF RECEIVER
CHAN B
FROM DIPOLE SWITCHES 2-8
DIPOLE SWITCH 9
DIPOLE 9
MATCHED RADIAL LINE
BUS A
BUS B
FROM DIPOLE SWITCHES 10-16
CONT TO OTHER DRIVERS
DIPOLE SWITCHING PATTERN
CONT TO OTHER DRIVERS
SOFT-SWITCH WAVEFORM GENERATOR
DOWN COUNT
NORTH PULSE LINE DRIVER
CLOCK LINERECEIVER
NORTH PULSE ADJUST (PRE-SET)
DELAY
DELAYED NORTH PULSE
1.6 kHz SCAN CLOCK
P/O BEARING PROCESSOR TIMING CARD

ANTENNA ARRAY AND DIPOLE COMMUTATION

SUB-SYSTEM BLOCK DIAGRAM

DF RECEIVER


ANTENNA SWITCH
RX FRONT END
2nd CONVERSION
3rd CONVERSION AND FINAL IF
PHASE DET.
117-137
20
30
0.80
2.2
0.050
0.2
0.015
RF AGC
LO-1 SYNTH.
LO-2 27.8 MHz
IF AGC
LO-3 2.4 MHz
RF AGC
IF AGC
PRESET OUTPUT LEVEL
FROM CH.2
TO BEARING PROCESSOR
-107
-27
-84
-34
-91
-41
-86
-56
-53
-23
-20
-18
LEGEND:
FREQ. MHz
BW MHz
dBm min.
dBm max.

BEARING PROCESSOR SUB-SYSTEM

FUNCTIONAL OBJECTIVE
- Computation of the angle of bearing
- System test analysis

PRE-SCAN CYCLE AND CORRECTION TO PHASE DETECTOR
- Handling of phase angle samples in excess of 180°
- Correction of phase detector ambiguity

INTEGRATION OF NOISE
- integration of phase detector output samples
- statistical averaging of bearing readout over a period of time
- automatic selection of integration constant

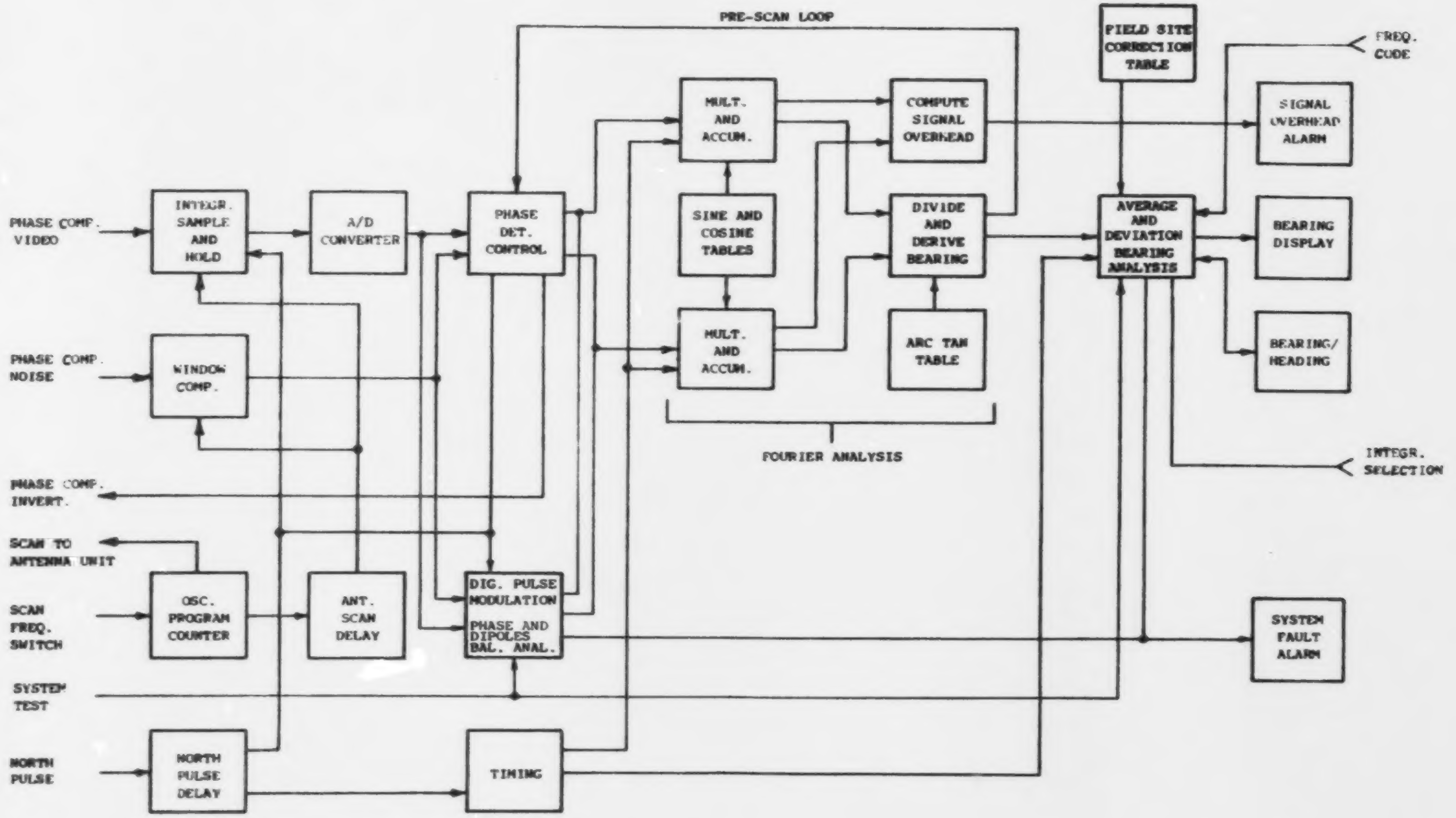
FOURIER ANALYSIS
- angle of bearing $= \tan^{-1} \left[\frac{\sum_{i=o}^{15} X_i \ \text{Sin} \ 22..5^\circ \ i}{\sum_{i=o}^{15} X_i \ \text{Cos} \ 22.5^\circ \ i} \right]$

  where X_i = sample of phase for each dipole pair selected

SIGNAL OVERHEAD
- computation of angle of elevation from amplitude of phase waveform
- trigger of OVHD light

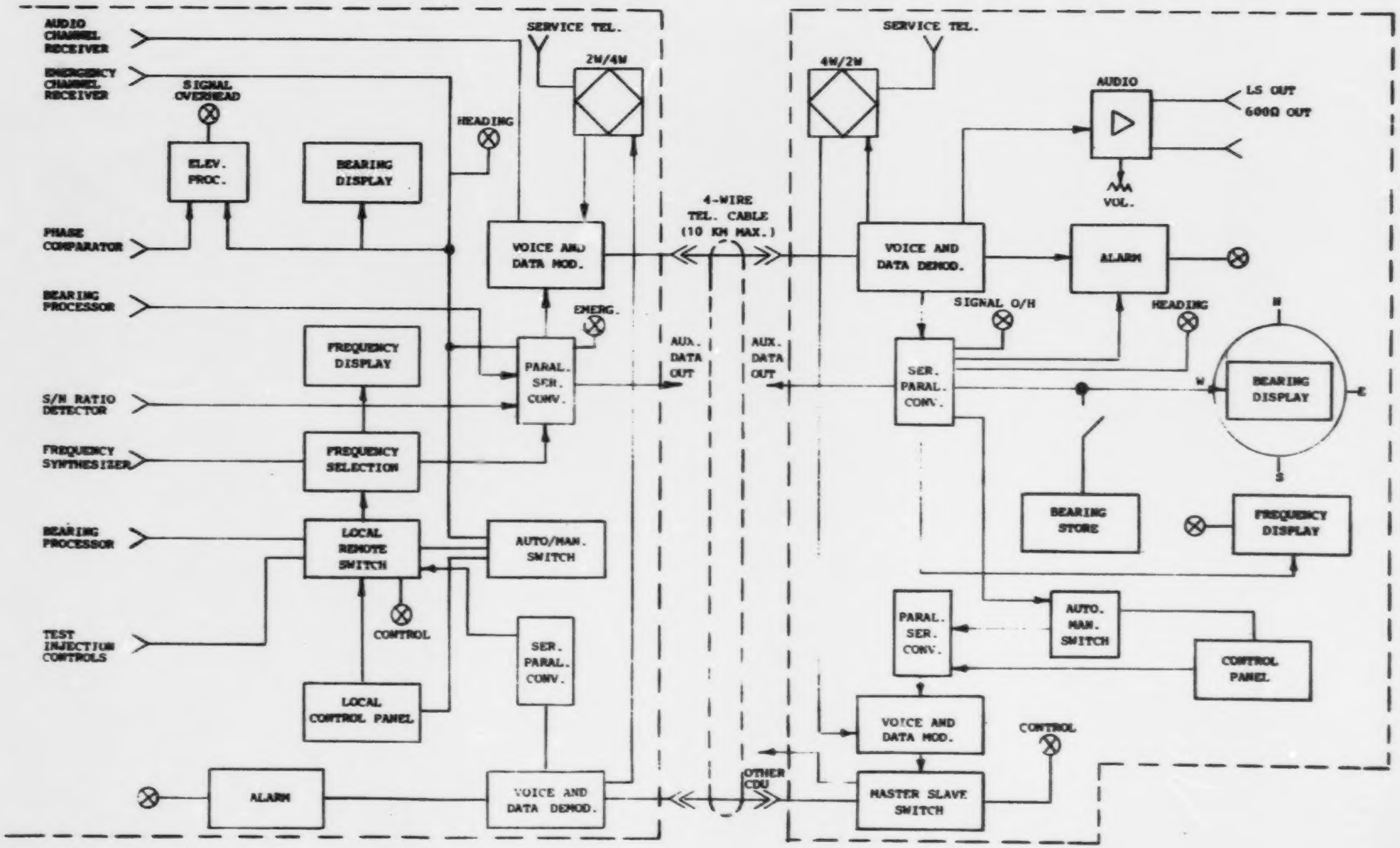
SYSTEM TEST
- digital pulse modulation of phase waveform samples
- computation of d.c. offset (receiver phase balance)
- analysis of dipole faults
- computation of bearing error

BEARING PROCESSOR



PRE-SCAN LOOP
PHASE COMP. VIDEO
INTEGR. SAMPLE AND HOLD
A/D CONVERTER
PHASE DET. CONTROL
MULT. AND ACCUM.
SINE AND COSINE TABLES
MULT. AND ACCUM.
COMPUTE SIGNAL OVERHEAD
DIVIDE AND DERIVE BEARING
ARC TAN TABLE
FOURIER ANALYSIS
FIELD SITE CORRECTION TABLE
AVERAGE AND DEVIATION BEARING ANALYSIS
FREQ. CODE
SIGNAL OVERHEAD ALARM
BEARING DISPLAY
BEARING/ HEADING
INTEGR. SELECTION
PHASE COMP. NOISE
WINDOW COMP.
PHASE COMP. INVERT.
SCAN TO ANTENNA UNIT
SCAN FREQ. SWITCH
OSC. PROGRAM COUNTER
ANT. SCAN DELAY
DIG. PULSE MODULATION
PHASE AND DIPOLES BAL. ANAL.
SYSTEM FAULT ALARM
SYSTEM TEST
NORTH PULSE
NORTH PULSE DELAY
TIMING

OPERATOR AND RECEIVER CONTROL/DISPLAY


AUDIO CHANNEL RECEIVER
EMERGENCY CHANNEL RECEIVER
SIGNAL OVERHEAD
ELEV. PROC.
BEARING DISPLAY
HEADING
SERVICE TEL.
2W/4W
PHASE COMPARATOR
VOICE AND DATA MOD.
BEARING PROCESSOR
EMERG.
FREQUENCY DISPLAY
PARAL. SER. CONV.
S/N RATIO DETECTOR
FREQUENCY SYNTHESIZER
FREQUENCY SELECTION
BEARING PROCESSOR
LOCAL REMOTE SWITCH
AUTO/MAN. SWITCH
TEST INJECTION CONTROLS
CONTROL
SER. PARAL. CONV.
LOCAL CONTROL PANEL
ALARM
VOICE AND DATA DEMOD.
4-WIRE TEL. CABLE (10 KM MAX.)
AUX. DATA OUT
AUX. DATA OUT
OTHER CDU
SERVICE TEL.
4W/2W
AUDIO
LS OUT
600Ω OUT
VOL.
VOICE AND DATA DEMOD.
ALARM
SIGNAL O/H
HEADING
N
W
E
S
SER. PARAL. CONV.
BEARING DISPLAY
BEARING STORE
FREQUENCY DISPLAY
PARAL. SER. CONV.
AUTO. MAN. SWITCH
CONTROL PANEL
VOICE AND DATA MOD.
CONTROL
MASTER SLAVE SWITCH

SELF-TEST FACILITY

NEW DESIGN CONCEPT

- Generation of test signal
- Injection of test signal through the Omni antenna
- Analysis of dipole pulses
- Display of test results

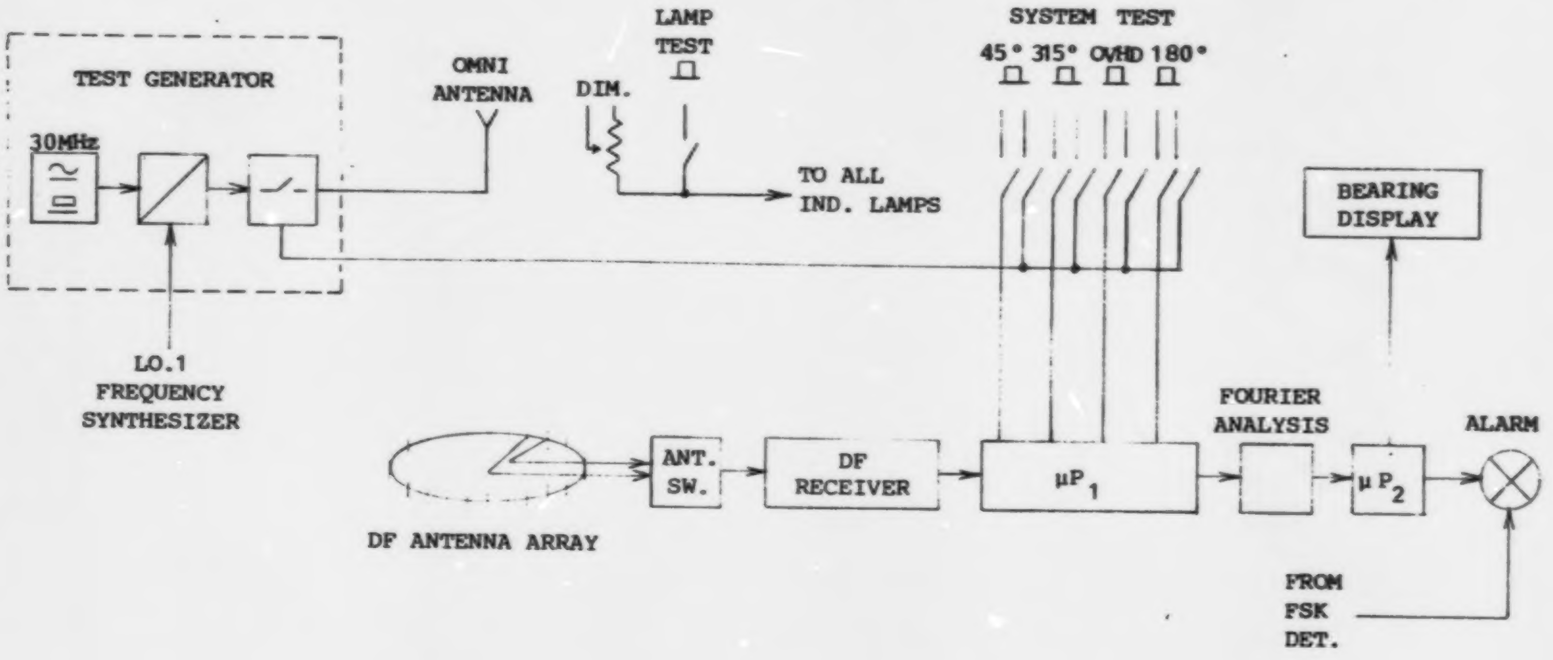
SEQUENCE OF ANALYSIS (performed by microprocessor 1)

- Modulation of phase detector output pulses (45°, 315° or 180°)
- Computation of d.c. offset ($<\pm 15^\circ$ receiver phase balance)
- Check on pulse sample noise (faulty dipole or switch)
- Computation of dipole unbalance ($<15^\circ$ peak-to-peak)

ALARM TRIGGER

- Any out-of-limit conditions reported by microprocessor 1
- Bearing readout error $>0.5^\circ$ computed by microprocessor 2

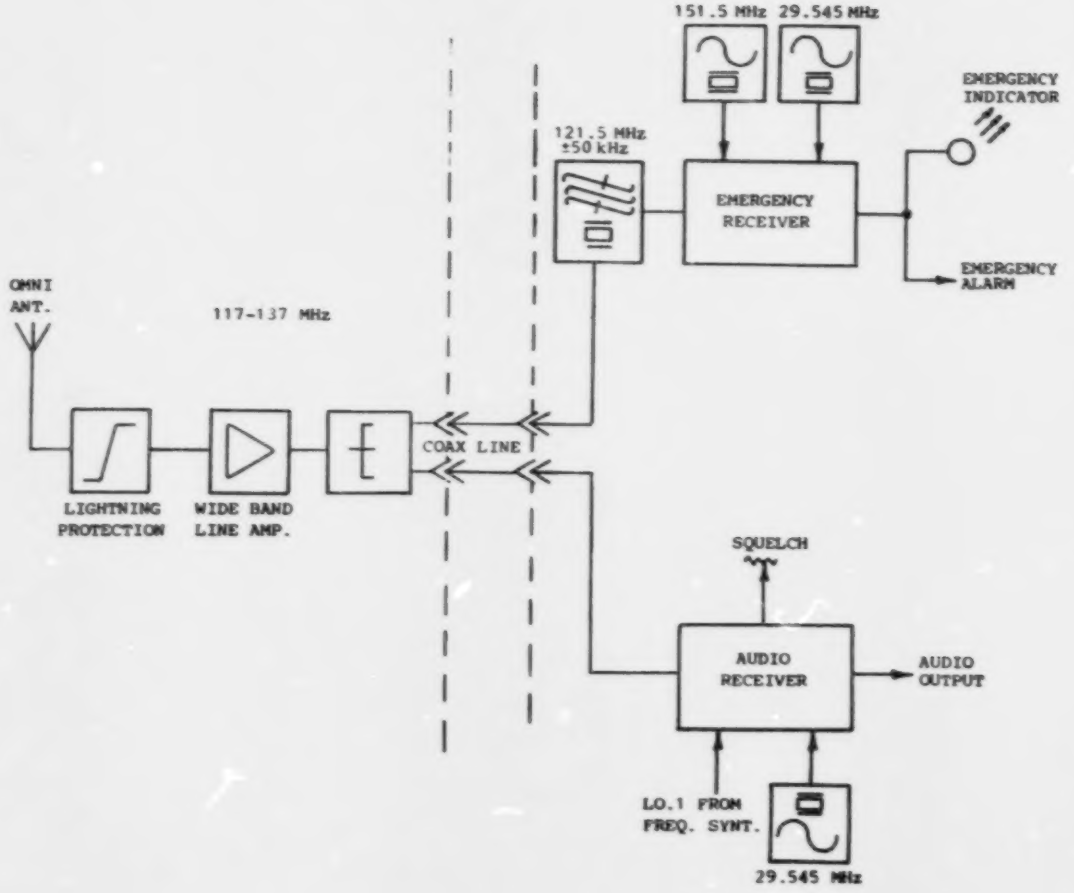
SELF-TEST FACILITY


TEST GENERATOR
30MHz
LO.1
FREQUENCY
SYNTHESIZER
OMNI
ANTENNA
DIM.
LAMP
TEST
TO ALL
IND. LAMPS
SYSTEM TEST
45° 315° OVHD 180°
BEARING
DISPLAY
DF ANTENNA ARRAY
ANT.
SW.
DF
RECEIVER
µP1
FOURIER
ANALYSIS
µP2
ALARM
FROM
FSK
DET.

TEST BUTTONS

- System Test - 45° or 315° display computed bearing
- OVHD - pulse modulation reduced in amplitude to simulate 60° elevation
- 180° - maintenance test position for system troubleshooting (Test Generator ON)

OMNI-DIRECTIONAL RECEIVERS


OMNI ANT.
117-137 MHz
LIGHTNING PROTECTION
WIDE BAND LINE AMP.
COAX LINE
121.5 MHz ±50 kHz
151.5 MHz
29.545 MHz
EMERGENCY RECEIVER
EMERGENCY INDICATOR
EMERGENCY ALARM
SQUELCH
AUDIO RECEIVER
AUDIO OUTPUT
LO.1 FROM FREQ. SYNT.
29.545 MHz

APPENDIX 3

MONTHLY PROGRESS REPORTS

NO. 11, 12, and 13

BAYLY
ENGINEERING
LIMITED

AEG
a member of the
AEG TELEFUNKEN group

DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 11

For the Period May 1 to July 30, 1983

DSS File No.: 12ST.T8200-1515
Bayly Reference no.: S.O. 35834

Distribution

TDC (5)
Science Procurement Manager (1)

1. SCOPE

This is the eleventh Progress Report on the development of the Quasi-Doppler RDF system, covering the period from May 1, 1983 to July 30, 1983. During the reporting period, the project was re-evaluated, resulting in the recent amendment of the contract.

2. LIST OF PERSONNEL (7.1.1)

The project team has been put together at the Bayly, Ajax operation, as follows:

1. Z.A. Krajewski - System Engineer
2. G. Hormann - Circuit Design
3. R. Beck - Mechanical Design
4. W. Ng - Software Development
5. F. Baehr - Digital Design
6. P. Bayer - Technologist
7. R. Anderson - Material Co-ordination
8. S. Hore - Filter Design
9. F. Weilandt - Antenna and Feed System Modification
10. R. Menkal - Project Manager
11. Supporting Staff

3. CURRENT STATUS (7.1.2)

3.1 Estimated work completed: 70%

3.2 Estimated elapsed time: 60%

3.3 Project is on schedule.

3.4 Project is within agreed financial limitations.

4. WORK ACCOMPLISHED (7.1.3)

The work accomplished during the reporting period:

4.1 The electronic equipment was removed from Norman Rogers Airport and installed in the laboratory at Ajax, as a reference system.

4.2 The equipment reconfiguration, electrically and mechanically, has been completed.

4.3 PCB's (Printed Circuit Boards) re-design and clean-up has been completed.

4.4 Seventy percent of the PCB's have been built and tested.

4.5 The system self test requirement has been re-defined, the hardware and software requirement is being implemented.

5. PROBLEM AREAS (7.1.4)

No problem areas have been encountered to date. Due to the vacation period, we have experienced delays in deliveries from outside vendors of some components.

6. WORK TO BE ACCOMPLISHED DURING AUGUST 1983 (7.1.5)

6.1 Antenna structure to be modified and new antenna feed system installed.

6.2 Production of the pre-production prototype system to be completed.

6.3 Factory sub-system and system tests to be completed.

6.4 Field test plans to be finalized and published.

6.5 Equipment to be installed at Norman Rogers Airport, Kingston, and tested prior to demonstration to TDC and Transport Canada during the week of August 29, 1983.

6.6 Documentation for Phase I and Phase II, per amendment to the contract, to be completed.

7. ACTION REQUIRED BY TDC (7.1.6)

Attendance at the Progress Meeting being held at Bayly Engineering during the wek of August 15, 1983.

8. SUB-CONTRACTS AND MEETINGS (7.1.7)

8.1 No major sub-contractors, or outside agencies, have been involved during the reporting period.

8.2 A meeting took place between TDC, Bayly Engineering and A.R.D. (a prospective purchaser of the Granby Division) on July 20, 1983.

9. OTHER INFORMATION (7.1.8)

The concerted effort during the reporting period, and the month of August, is aimed at having the pre-production prototype system ready for demonstration during the week of August 29, 1983, and to convince Transport Canada, the ultimate user of the system, that Bayly's RDF will meet their requirements.

BAYLY
ENGINEERING
LIMITED

a member of the
AEG-TELEFUNKEN group

DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 12

For the Period August 1 to August 31, 1983

DSS File No.:	12ST.T8200-1515
Bayly Reference no.:	S.O. 35834

Distribution

TDC (5)
Science Procurement Manager (1)
Transport Canada TANE (1) - V. Caloia

1.0 SCOPE

This is the twelfth Progress Report on the development of the Quasi-Doppler RDF system, covering the period from August 1, 1983 to August 31, 1983. During the reporting period, the equipment was assembled in plant, tested and moved to the test site at Norman Rogers Airport, Kingston.

2.0 LIST OF PERSONNEL (7.1.1)

The project team remained the same as per Progress Report No. 11.

3.0 CURRENT STATUS (7.1.2)

3.1 Estimated work completed 85%

3.2 Estimated elapsed time 70%

3.3 Project is two (2) weeks late.

3.4 Project is within agreed financial limitations.

4.0 WORK ACCOMPLISHED (7.1.3)

The work accomplished during the reporting period was as follows:

4.1 The antenna structures were modified and new feed system installed.

4.2 Production of pre-production prototype system completed.

4.3 Factory sub-system and system test completed.

4.4 Field test plans finalized and published.

4.5 Electronic equipment installed at Norman Rogers Airport was aligned and tested.

4.6 Documentation for Phase I and part of Phase II completed.

5.0 PROBLEM AREAS (7.1.4)

After installation at Norman Rogers Airport, the equipment experienced usual 'infant mortality'. In addition, due to high humidity, the equipment, together with test equipment, was exposed to a high level of condensation in the 'off' position, one day prior to demonstration, resulting in additional complications.

6.0 WORK TO BE ACCOMPLISHED DURING SEPTEMBER 1983

6.1 Demonstration to TDC and Transport Canada.

6.2 Rectify any problems resulting from field tests.

6.3 Finalize documentation for Phase II per amendment to the contract of July 15, 1983.

6.4 Discuss test results with TDC and Transport Canada

6.5 Prepare proposal for supply of 20 ATC VHF/DF systems to Transport Canada

7.0 ACTION REQUIRED BY TDC (7.1.6)

Attend the field demonstration.

8.0 SUB-CONTRACTS AND MEETINGS (7.1.7)

8.1 No major sub-contractors, or outside agencies, have been involved during the reporting period.

8.2 A meeting took place at Bayly between Transport Canada (Air and Marine), TDC and Bayly Engineering on August 18, 1983 to review the project.

9.0 OTHER INFORMATION (7.1.8)

It is hoped that the concerted effort during the reporting period, and the resulting demonstration, will convince Transport Canada, (TANE), that Bayly's VHF/DF system will meet their requirements.

BAYLY
ENGINEERING
LIMITED

AEG
a member of the
AEG TELEFUNKEN group

DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE
RADIO DIRECTION FINDER

Progress Report No. 13

For the Period September 1 to September 30, 1983

DSS File No.: 12ST.T8200-1515
Bayly Reference no.: S.O. 35834

Distribution

TDC (5)
Science Procurement Manager (1)
Transport Canada TANE (1) - V. Caloia

1.0 SCOPE

This is the thirteenth Progress Report on the development of the Quasi-Doppler RDF system, covering the period from September 1, 1983 to September 30, 1983. During the reporting period, the equipment was installed at Norman Rogers Airport, Kingston, and demonstrated to Transport Canada and TDC.

2.0 LIST OF PERSONNEL (7.1.1)

The project team remained the same as per Progress Report No. 11.

3.0 CURRENT STATUS (7.1.2)

3.1	Estimated work completed	90%
3.2	Estimated elapsed time	80%

3.3 Project is on time.

3.4 Project is within agreed financial limitations.

4.0 WORK ACCOMPLISHED (7.1.3)

The work accomplished during the reporting period was as follows:

4.1 Demonstration to Transport Canada and TDC carried out.

4.2 Minor software problem has been cleared.

4.3 Work on proposal for supply of 20 ATC VHF/DF systems to Transport Canada is continuing.

5.0 PROBLEM AREAS

The software problem has been corrected, however, we propose to carry further work, aiming at simplifying the program and verification of the same in the field. We plan to approach TDC for additional support to cover this effort.

6.0 WORK TO BE ACCOMPLISHED DURING OCTOBER 1983

6.1 Finalize documentation for Phase II per amendment to the contract of July 15, 1983.

6.2 Discuss test results with TDC and Transport Canada, provided tenders to supply production quantities have been closed.

6.3 Finalize proposal for supply of 20 ATC VHF/DF systems to Transport Canada.

6.4 Carry out additional tests to verify revised software.

7.0 ACTION REQUIRED BY TDC (7.1.6)

Investigate possible additional support to cover the software work.

8.0 SUB-CONTRACTS AND MEETINGS (7.1.7)

8.1 No major sub-contractors, or outside agencies, have been involved during the reporting period.

8.2 No major meetings took place during the reporting period.

APPENDIX 4

SYSTEM FIELD PERFORMANCE TEST PLAN
AND PERFORMANCE CHARACTERISTICS

AUGUST 1983

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1.0 PRELIMINARY REQUIREMENTS

1.1 System Installation

The system field performance test procedures are to be performed on one complete system, including antenna, as installed at an operational site, in the frequency band 117.5 MHz to 136.5 MHz.

1.2 Calibration Circle

For the purposes of the tests, a calibration (azimuth) circle (see 3.0 and Figure 1) must be carefully marked out on the ground. Observe that the system North (0°) reference (preset adjustment) must agree with the 0° azimuth angle marked on the calibration circle.

1.3 Obstruction Clearance for Test

Remove small metal objects, e.g. wire, cans, boxes, tools, etc., to any location not less than 200 feet distance from the antenna tower. Remove large metal objects, e.g. vehicles, frames, ladders, etc., to any location not less than 400 feet distance from the antenna tower.

1.2 and 1.3 shall apply throughout the test.

1.4 System Operating Conditions

Before starting the tests, a minimum 20 minute equipment warm-up period is required.

During the tests, the system is to be operated entirely from the front control/display panel on the Receiver Unit. For this purpose, the LOCAL/REMOTE switch toggle must be set to the LOCAL position.

2.0 ARRANGEMENT OF TEST PROCEDURES

The system field performance test procedures are arranged under Section 4.0 in test number with title, and the corresponding test log sheets. By performing the procedures in test number sequence, the handling and operation of test equipment is, to some extent, simplified. However, the procedure may be performed in any order.

3.0 TEST EQUIPMENT AND OTHER ITEMS REQUIRED

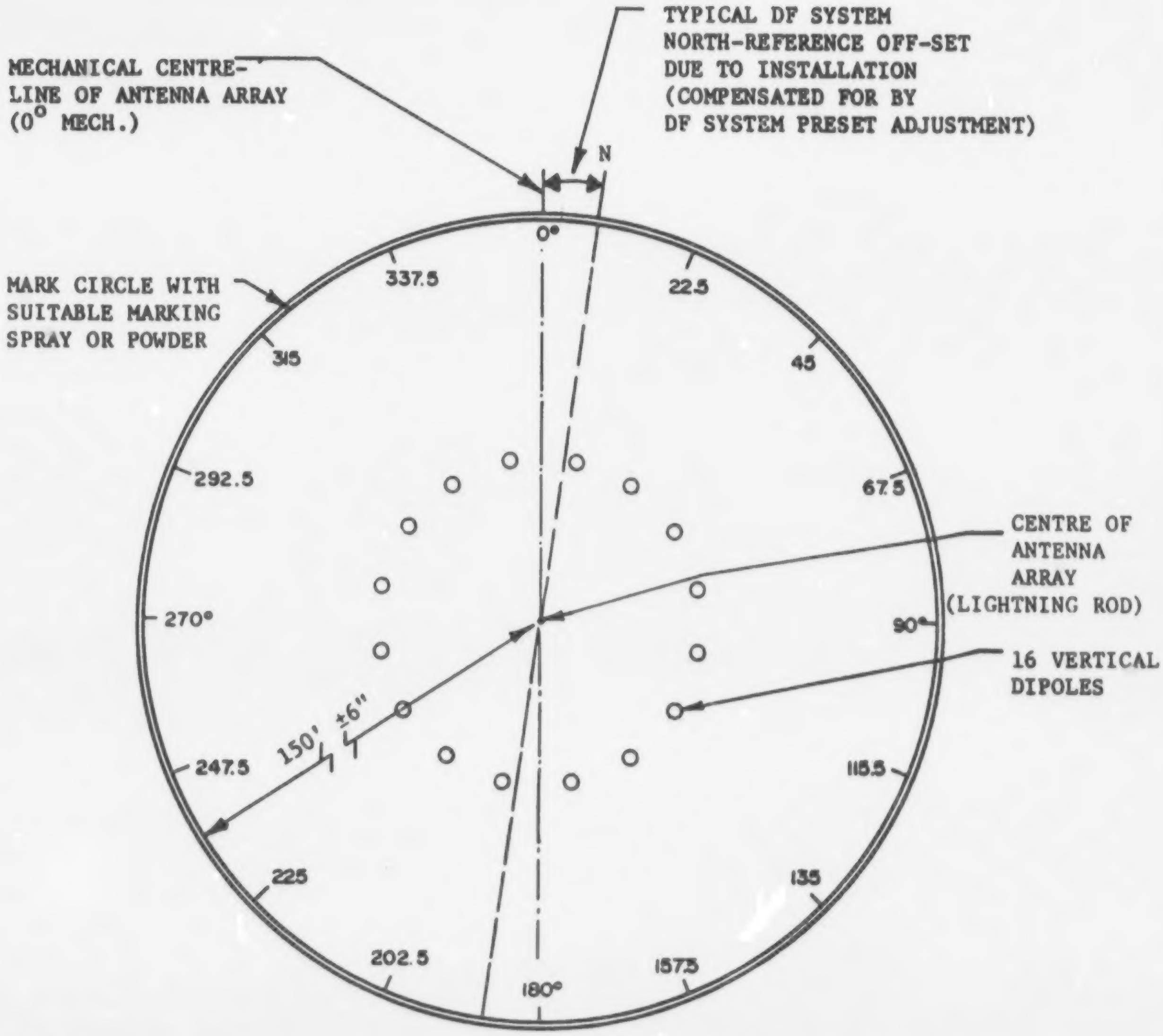
The following test equipment and other items are required in order to perform the system field performance test procedures. Where applicable, equivalent test equipment and items may be used.

Item	Qty.	Description/Type/Model
1	2	VHF Test Transmitter
2	1	VHF RF power amplifier
3	2	VHF Test Dipole
4	2	Tripod
5	2	Portable power generator, 120V AC, 0.5 kVA
6	1	VHF Field Strength Meter
7	1	Oscilloscope

4.0 FIELD PERFORMANCE TESTS

The field tests defined in this section are essentially the same as those performed during March 1983, and witnessed by TDC and Transport Canada. The limits have been updated to reflect the latest Transport Canada requirements and the re-designed equipment.

Perform the following tests in test number order (preferably). Enter all test results in the corresponding test log sheet(s).


MECHANICAL CENTRE-LINE OF ANTENNA ARRAY (0° MECH.)
TYPICAL DF SYSTEM NORTH-REFERENCE OFF-SET DUE TO INSTALLATION (COMPENSATED FOR BY DF SYSTEM PRESET ADJUSTMENT)
N
0°
337.5
22.5
MARK CIRCLE WITH SUITABLE MARKING SPRAY OR POWDER
315
45
292.5
67.5
CENTRE OF ANTENNA ARRAY (LIGHTNING ROD)
270°
90°
16 VERTICAL DIPOLES
150' ±6"
247.5
115.5
225
135
202.5
157.5
180°

N=θ° TRUE AZIMUTH SPECIFIED BY ATC REGULATIONS

NOTE: Azimuth degrees are for text reference only (do not mark).

FIGURE 1

CALIBRATION CIRCLE FOR ANTENNA ARRAY

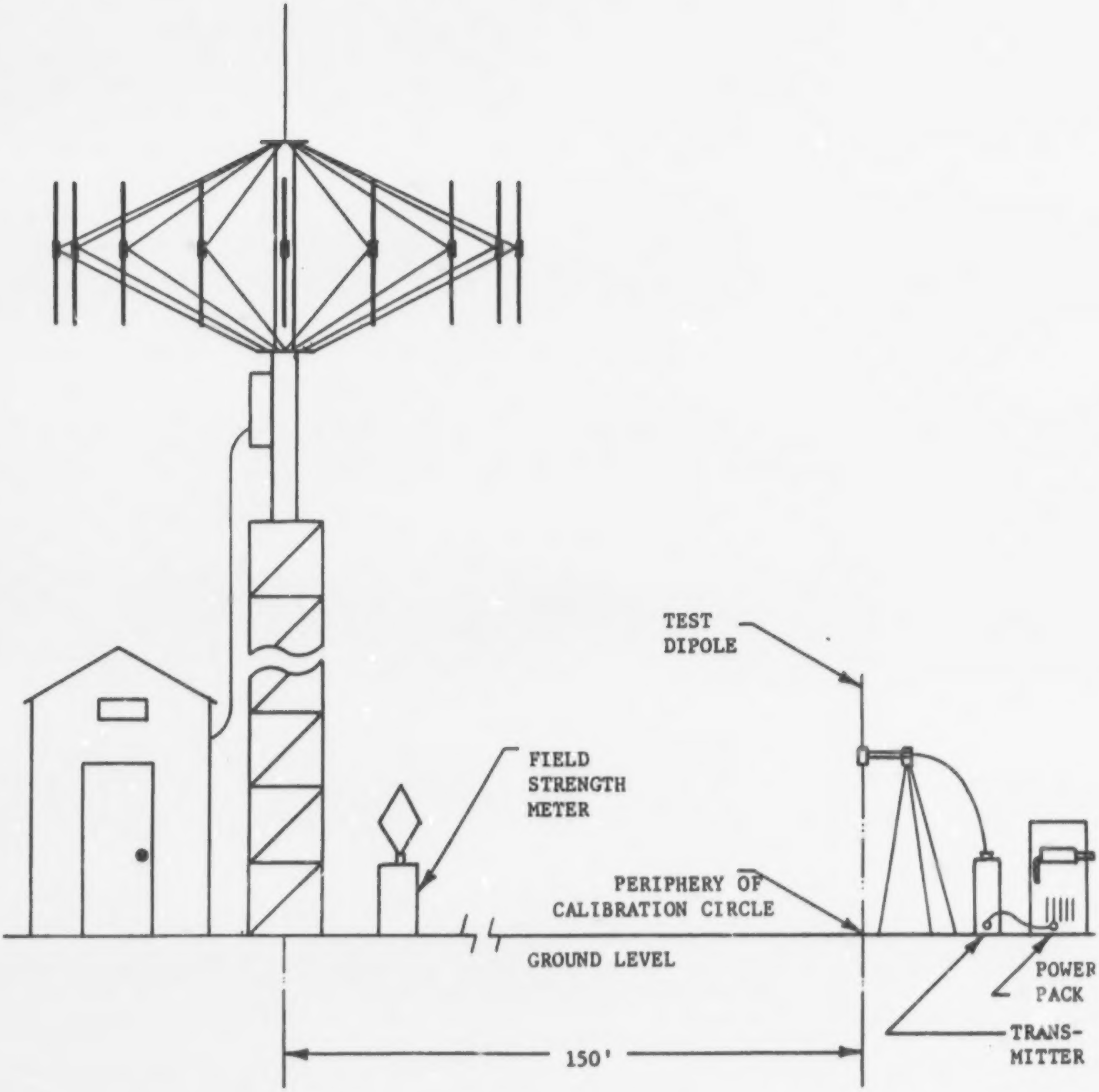

TEST DIPOLE
FIELD STRENGTH METER
PERIPHERY OF CALIBRATION CIRCLE
GROUND LEVEL
POWER PACK
TRANS-MITTER
150'

FIGURE 2

TEST SET-UP SCHEMATICAL VIEW

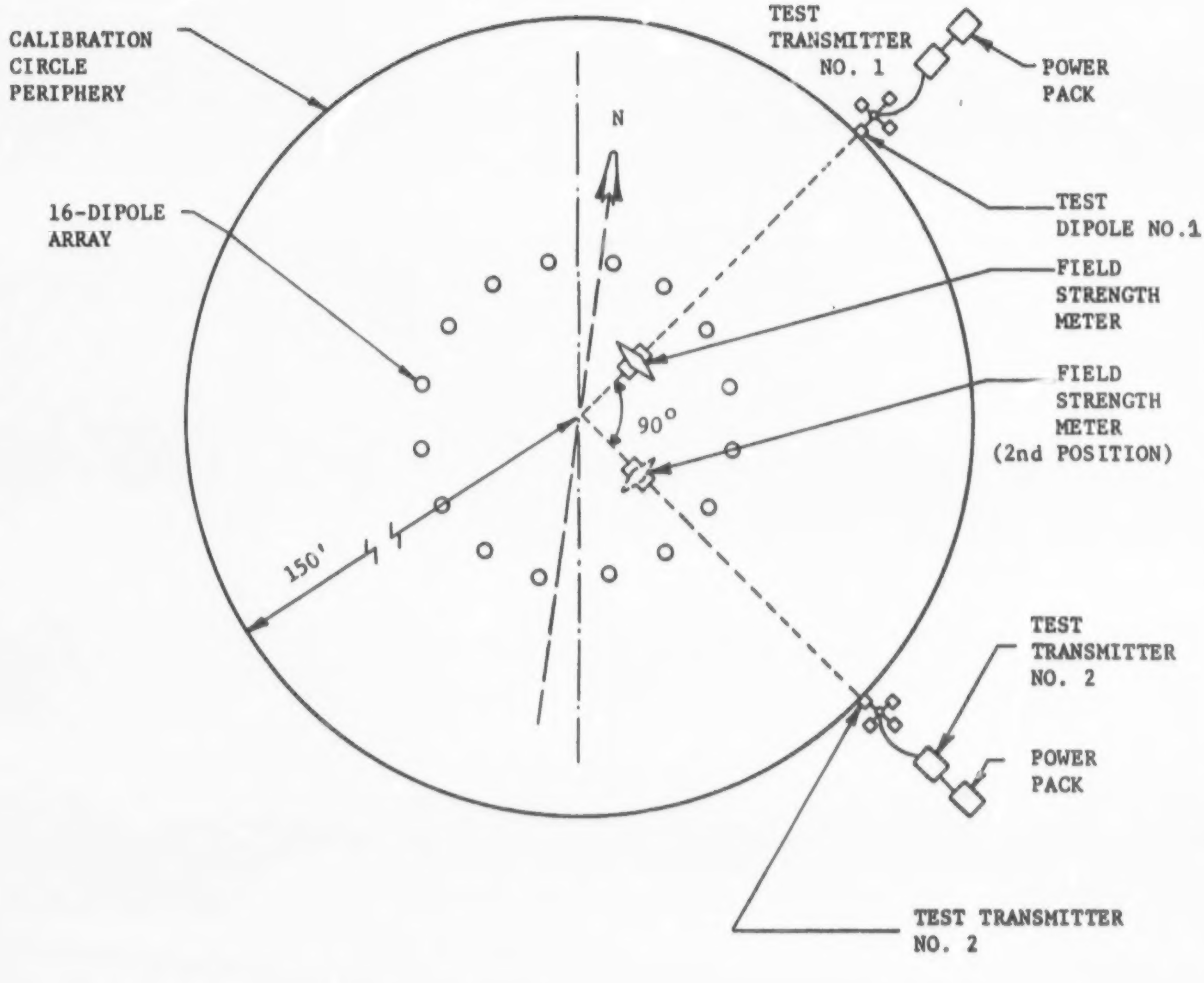

CALIBRATION CIRCLE PERIPHERY
16-DIPOLE ARRAY
N
TEST TRANSMITTER NO. 1
POWER PACK
TEST DIPOLE NO.1
FIELD STRENGTH METER
FIELD STRENGTH METER (2nd POSITION)
90°
150'
TEST TRANSMITTER NO. 2
POWER PACK
TEST TRANSMITTER NO. 2

FIGURE 3

TEST SET-UP FOR TWO TRANSMITTERS

4.1 TEST NO. 1 - SYSTEM DF SENSITIVITY (CW MODE)

4.1.1 Specification Limits

System sensitivity (vertical polarization):

≤5 µV/m for ≤3° BEARING readout spread.

4.1.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(1)
Item 3	Test Dipole	(1)
Item 4	Tripod	(1)
Item 5	Power Generator Pack	(1)
Item 6	Field Strength Meter	(1)

Mark out a calibration circle according to Figure 1.

4.1.3 Test Procedure

NOTE: Figure 2 is a pictorial view (at ground level) of the general test set-up.

(a) Set up the test dipole at any selected angle on the calibration circle (Figure 1).

(b) Connect the test transmitter to the test dipole and power pack.

(c) Ensure that the transmitter and auxiliary equipment are positioned behind the test dipole and outermost from the calibration circle.

(d) Position the field strength meter under the antenna array and within the array circumference. Ensure that the meter antenna is properly aligned with the test antenna.

(e) Select test frequency 118.250 MHz on test transmitter and on the DF system control panel.

(f) On the test transmitter, select modulation mode CW.

(g) Set test transmitter output level to obtain 5 uV/m reading on field strength meter. (NOTE: after Tx set-up, remove FSM from testing area).

(h) On the DF system control panel, observe BEARING display readout, and record the minimum and maximum readings obtained over at least 10 consecutive update readings. (NOTE: 'update' means that the bearing readout changes slightly for successive bearing calculations made by the equipment). Enter min./max. readings in the appropriate spaces on TEST NO. 1 LOG SHEET.

NOTE: 'Update' is a full cycle of computation and it corresponds in time to the duration of the integration constant (0.2 sec. to 1 sec.). Hence, 10 update readings is no longer than 10 seconds.

(i) Repeat steps (e) through (g) except set testing frequency to 128.6 MHz.

(j) Repeat steps (e) through (g) except set testing frequency to 133.0 MHz.

TEST NO. 1 LOG

System DF Sensitivity (CW Mode)

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		BEARING SPREAD (Degrees)
	Min.	Max.	
118.250	_____	_____	__________
128.600	_____	_____	__________
133.000	_____	_____	__________

4.2 TEST NO. 2 - EFFECT OF CONTROLLED VARIATIONS IN TEST SIGNAL OPERATING CONDITIONS

4.2.1 Purpose of Test

This test is intended to record the effect produced on the BEARING display readout due to controlled variations in the test signal operating conditions. The information obtained is to be recorded in the appropriate spaces of TEST NO. 2 LOG SHEET. Observe that there are no specifications to be met. These test results are to be regarded as INFORMATION ONLY.

4.2.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(1)
Item 2	RF Power Amplifier	(1)
Item 3	Test Dipole	(1)
Item 4	Tripod	(1)
Item 5	Power Generator Pack	(1)
Item 6	Field Strength Meter	(1)

4.2.3 Test Procedure

NOTE: Figure 2 is a pictorial view (at ground level) of the general test set-up.

(a) Set up the test dipole at any selected angle on the calibration circle.

(b) Connect the test transmitter to the test dipole and the power pack.

(c) Ensure that the test transmitter and auxiliary equipment are positioned behind the test dipole and outermost from the calibration circle.

(d) Position the field strength meter under the antenna array and within the array circumference. Ensure that the meter antenna is properly aligned with the test antenna.

(e) On the DF system control panel, select frequency of 127.0 MHz.

(f) On the test transmitter, select frequency of 127.0 MHz and modulation mode CW.

(g) Set test transmitter output level to obtain 50 µV/m reading on field strength meter. (After use, remove the FSM from the testing area).

(h) On the DF system control panel, observe BEARING display readout and record the minimum and maximum readings obtained over at least 10 consecutive update readings. (NOTE: 'update' means that the bearing readout changes slightly for successive bearing calculations made by the equipment). Enter the min./max. readings in the appropriate spaces of TEST NO. 2 LOG SHEET.

(i) Use the min./max. readings recorded in step (h) above to calculate the average (arithmetic mean) value of each BEARING readout). Enter this value in the appropriate spaces on TEST NO. 2 LOG SHEET.

(j) Repeat steps (f) through (i) above, except set test transmitter frequency to 127.030 MHz (approx. +25 ppm detune from channel centre frequency). **DO NOT** change the DF system channel frequency of 127.0 MHz.

(k) Repeat steps (f) through (i) except set test transmitter frequency of 127.060 MHz (approx. +50 ppm detune from channel centre frequency).

(l) Repeat steps (f) through (i) except set test transmitter frequency to 126.970 MHz (approx. -25 ppm detune from channel centre frequency).

(m) Repeat steps (f) through (i) except set test transmitter frequency to 126.940 MHz (approx. -50 ppm detune from channel centre frequency).

(n) Repeat steps (f) through (i) above, except on test transmitter set modulation mode to AM, 1000 Hz tone modulation depth 30%.

(o) Repeat steps (f) through (i) except on test transmitter, set modulation mode to FM, 1000 Hz tone, modulation deviation 3 kHz.

(p) Check that the test transmitter is set to 127.0 MHz, CW mode, and 50 V/m on field strength meter. (After Tx set-up, remove FSM from testing area). The DF system must remain on channel frequency 127.0 MHz.

(q) Repeat steps (h) and (i)

NOTE: In step (r) following, the larger field strength requirements will necessitate the connection of test equipment Item 2 (RF power amplifier) to Item 1 (test transmitter).

(r) Repeat step (p) (with (h) and (i)) the test transmitter output producing field strength of 5, 10, 50, 100, 300, 1,000, 3,000, and 10,000 µV/m.

TEST NO. 2 LOG

Effect of Controlled Variations in Signal Operating Conditions

1. FREQUENCY DETUNING (CW MODE)

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
	Min.	Max.		
127.000	____	____	______ (Ref.)	XXXX
127.030	____	____	______	______
127.060	____	____	______	______
126.970	____	____	______	______
126.940	____	____	______	______

2. AMPLITUDE MODULATION (AM MODE) - 30% AT 1 kHz

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
	Min.	Max.		
127.000 (CW Mode)	____	____	______	______
127.030 (AM Mode)	____	____	______	______
__________	____	____	______	______
__________	____	____	______	______

3. SIGNAL STRENGTH (CW MODE, 127 MHz FREQUENCY)

TEST SIGNAL STRENGTH	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
	Min.	Max.		
5 uV/m	____	____	______	______
10 uV/m	____	____	______	______
50 uV/m	____	____	______	______ (Ref.)
100 uV/m	____	____	______	______
300 uV/m	____	____	______	______
1 mV/m	____	____	______	______
3 mV/m	____	____	______	______
100 mV/m	____	____	______	______

4.3 TEST NO. 3 - DF SYSTEM INSTALLATION ACCURACY (CW MODE)

NOTE: Test No. 3 begins with an initial check of the DF system NORTH REFERENCE offset with the antenna mounted on the turntable and locked in the reference position. Subsequently, the antenna is rotated in calibrated steps and bearings are obtained for each antenna position.

4.3.1 Specification Limits

DF accuracy ±1.5° BEARING (Target ±1.0°) readout error with respect to relative azimuth angle for three frequencies: 118.25 MHz, 128.6 MHz and 133.0 MHz.

4.3.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(1)
Item 3	Test Dipole	(1)
Item 4	Tripod	(1)
Item 5	Power Generator Pack	(1)
Item 6	Field Strength Meter	(1)

4.3.3 Test Procedure

NOTE: Figure 1 shows a typical DF system installation offset of the antenna array centreline (0° mechanical) with respect to true azimuth (Ta)°. This offset will be electronically preset during installation.

(a) Refer to Figure 1. Locate the 0° true azimuth line (marked 'N') according to Air Traffic Control (ATC) regulations. This 0° line is marked at a distance of 180 feet in the 'N' direction with an angular accuracy of 0.1°. The purpose of this line is to place the test dipole (with transmitter) on the line, and as far distance from the antenna array as may be practicable.

(b) Set up the test dipole on the 'N' line marker.

(c) Connect the test transmitter to the test dipole and power pack.

(d) Ensure that the test transmitter and power pack are positioned behind the test dipole (with respect to testing direction).

(e) On the test transmitter, select modulation mode CW.

(f) Select test frequency 118.25 MHz on the test transmitter and on the DF system control panel.

(g) Observe the BEARING display readout noting the minimum and maximum indications over approx. 10 seconds. Make an entry of minimum and maximum values.

(h) Set the antenna turntable to zero position.

(i) Set test transmitter output level to obtain 50 µV/m on the field strength meter. (NOTE: as reference, use the output level obtained under 5.1.5 (g) and add 20 dB).

(j) Report bearing readouts for 5 uV/m and 1 mV/m field strength, and also report test for 128.6 MHz and 133.0 MHz for the three signal levels.

(k) Move the antenna turntable to the next position, etc. and repeat the tests, making note of the new bearing readings.

(l) On Test No. 3 Log Sheet enter the bearing readings and bearing error.

NOTE 1:

The test dipole set-up angles specified hereunder for the calibration circle are antenna array mechanical angles, starting with 0° and proceeding through 11.25° intervals to cover 360°. These angles are accurate to ±0.1°, by virtue of mechanical precision of the turntable.

NOTE 2:

The test dipole position on the calibration circle is required to have an accuracy of ±0.1° (corresponding to ±3 inches along the arc of the circle). The test dipole must not be moved for the duration of this test.

NOTE 3:

The specified maximum bearing error is the sum of the system installation errors. It should not include a North reference error, which may be due to local re-radiation at the transmitter site.

4.3.4 SYSTEM INSTALLATION ACCURACY INCLUDING FIELD EFFECTS (CW MODE)

4.3.4.1 Specification Limit

The DF system shall meet the system site accuracy of ±3.0°.

Repeat the tests given in 4.3 (above) with the DF antenna in the fixed position, and test dipole and test transmitter moved around the calibration circle in steps of 22.5°, and enter reading in the log tables and calculate the bearing error.

TEST NO. 3 LOG

DF System Installation Accuracy (CW Mode)

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	0/360	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
2	11.25	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
3	22.50	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
4	33.75	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING Min.	BEARING READING Max.	ERROR CALC. Min.	ERROR CALC. Max.	BEARING READING Min.	BEARING READING Max.	ERROR CALC. Min.	ERROR CALC. Max.	BEARING READING Min.	BEARING READING Max.	ERROR CALC. Min.	ERROR CALC. Max.
5	45.00	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
6	56.25	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
7	67.50	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
8	78.75	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
9	90.00	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
10	101.25	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
11	112.50	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
12	123.75	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
13	135.00	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
14	146.25	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
15	157.50	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
16	168.75	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
17	180.00	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
18	191.25	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
19	202.50	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
20	213.75	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
21	225.00	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
22	236.25	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
23	247.50	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
24	258.75	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

3.1 Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
25	270.00	5 µV/m												
		50 µV/m												
		1 mV/m												
26	281.25	5 µV/m												
		50 µV/m												
		1 mV/m												
27	292.50	5 µV/m												
		50 µV/m												
		1 mV/m												
28	303.75	5 µV/m												
		50 µV/m												
		1 mV/m												
29	315.00	5 µV/m												
		50 µV/m												
		1 mV/m												

3.1 **Tx FIXED AT 0° AZIMUTH AND DF ANTENNA ROTATED** (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
DF ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
30	326.25	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
31	337.50	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
32	348.75	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

TEST NO. 3 LOG

DF System Installation Accuracy (CW Mode)

3.2 DF ANTENNA FIXED AT 0° AZIMUTH AND Tx ANTENNA MOVED AROUND

FREQUENCY (MHz)			118.25				128.60				133.00			
Tx ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	0/360	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
2	22.5	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
3	45.0	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
4	67.5	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

3.2 **DF ANTENNA FIXED AT 0° AZIMUTH AND Tx ANTENNA MOVED AROUND** (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
Tx ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5	90.0	5 µV/m												
		50 µV/m												
		1 mV/m												
6	112.5	5 µV/m												
		50 µV/m												
		1 mV/m												
7	135.0	5 µV/m												
		50 µV/m												
		1 mV/m												
8	157.5	5 µV/m												
		50 µV/m												
		1 mV/m												
9	180.0	5 µV/m												
		50 µV/m												
		1 mV/m												

3.2 DF ANTENNA FIXED AT 0° AZIMUTH AND Tx ANTENNA MOVED AROUND (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
Tx ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
10	202.5	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
11	225.0	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
12	247.5	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
13	270.0	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___
14	292.5	5 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		50 µV/m	___	___	___	___	___	___	___	___	___	___	___	___
		1 mV/m	___	___	___	___	___	___	___	___	___	___	___	___

3.2 **DF ANTENNA FIXED AT 0° AZIMUTH AND Tx ANTENNA MOVED AROUND** (Cont'd)

FREQUENCY (MHz)			118.25				128.60				133.00			
Tx ANT. POS.	REF. (Deg.)	FIELD STRENGTH	BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.		BEARING READING		ERROR CALC.	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
15	315.0	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____
16	337.5	5 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		50 µV/m	____	____	____	____	____	____	____	____	____	____	____	____
		1 mV/m	____	____	____	____	____	____	____	____	____	____	____	____

4.4 TEST NO. 4 - BEARING READOUT CHANGE WITH RESPECT TO POLARIZATION ANGLE (CW MODE)

4.4.1 Specification Limits

Bearing readout error for a test dipole angle of 45° from the vertical in a plane tangential to the calibration circle (see 5.4.3).

2° change from bearing readout made with the test antenna in the normal vertical position.

4.4.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(1)
Item 3	Test Dipole	(1)
Item 4	Tripod	(1)
Item 5	Power Generator Pack	(1)
Item 6	Field Strength Meter	(1)

4.4.3 Test Procedure

NOTE: Figure 2 is a pictorial view (at ground level) of the general test set-up.

(a) Set up the test dipole on the calibration circle at 0° reference. The test dipole must be vertical.

(b) Connect the test transmitter to the test dipole and power pack.

(c) Ensure that the test transmitter and auxiliary equipment are positioned behind the test dipole and outermost from the calibration circle.

(d) Set the antenna turntable to zero reference.

(e) Select test frequency 118.250 MHz on the test transmitter and on the DF system.

(f) On the test transmitter, select modulation mode CW.

(g) Set test transmitter output level to obtain 50 µV/m reading on the field strength meter.

(h) Observe the test readout appearing on the system control panel BEARING display and record this on TEST NO. 4 TEST LOG SHEET (in the appropriate space).

(i) Rotate the test dipole, clockwise, until it is at an angle 45° to the vertical. Maintain this test dipole angle.

(j) Repeat step (h).

(k) Rotate the test dipole anti-clockwise by 45° and repeat step (h).

(l) Reset the test dipole to its normal vertical angle.

(m) Repeat steps (e) through (k) except set testing frequency to 128.6 MHz.

(n) Repeat steps (e) through (k) except set testing frequency to 133.0 MHz.

(o) Repeat steps (a) through (n) for increments of 90° of the antenna turntable position angle.

TEST NO. 4 LOG

Bearing Readout Change WRT Polarization Angle

(Field Strength 50 µV/m)

FREQUENCY (MHz)		118.25	128.60	133.00
DF ANTENNA POSITION	Tx ANTENNA POLARIZATION			
0°	Vertical °	____	____	____
	+45°	____	____	____
	-45°	____	____	____
	Change from Vertical	____	____	____
90°	Vertical °	____	____	____
	+45°	____	____	____
	-45°	____	____	____
	Change from Vertical	____	____	____
180°	Vertical °	____	____	____
	+45°	____	____	____
	-45°	____	____	____
	Change from Vertical	____	____	____
270°	Vertical °	____	____	____
	+45°	____	____	____
	-45°	____	____	____
	Change from Vertical	____	____	____

4.5 TEST NO. 5 - ADJACENT CHANNEL BREAKTHROUGH EFFECT ON BEARING READOUT (CW MODE)

4.5.1 Specification Limits

Breakthrough effect, due to a properly centred 'unwanted' adjacent channel test signal, displaced 90° from a 'wanted' test signal, and within the following field strength constraints: unwanted signal 1.5 mV/m and 30 dB above the level of the wanted signal (50 µV/m).

The bearing readout change due to the above unwanted signal shall be less than ±1°.

4.5.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(2)
Item 2	RF Power Amplifier	(1)
Item 3	Test Dipole	(2)
Item 4	Tripod	(2)
Item 5	Power Generator Pack	(2)
Item 6	Field Strength Meter	(1)

4.5.3 Test Procedure

NOTE: Figure 2 is a pictorial view (overhead) of the general test set-up.

(a) Set up one test dipole (No. 1) on the calibration circle, at any selected azimuth angle. (e.g. zero ref. position).

(b) Set up the other test dipole (No. 2) on the circle at a position angularly displaced from dipole No. 1 by 270° in a clockwise direction (overhead view).

(c) Connect test transmitter No. 1 (without RF power amplifier) to test dipole No. 1 and to its power pack.

(d) Connect test transmitter No. 2 (with RF power amplifier to test dipole No. 2 and to its power pack. **DO NOT** switch on this transmitter until it is required.

(e) Ensure that the test transmitters and auxiliary equipment are positioned behind the test dipoles and outermost from the calibration circle.

(f) Set the antenna turntable position to zero reference.

(g) On test transmitter No. 1, select test frequency 128.600 MHz and modulation mode CW. Select DF system frequency 128.600 MHz.

(h) Set test transmitter No. 1 output level to obtain 50 µV/m.

(i) Record the BEARING display readout on TEST NO. 5 LOG SHEET.

(j) On test transmitter No. 2, select test frequency 128.625 MHz (adjacent channel) and modulation mode CW.

(k) Set test transmitter No. 2 output level to obtain 1.5 mV/m (30 dB above test transmitter No. 1 level).

(l) Record the BEARING display readout on TEST NO. 5 LOG SHEET.

(m) Repeat steps (j) through (l) test transmitter No. 2 (only) set to frequency 128.620 MHz.

(n) Repeat steps (j) through (l) test transmitter No. 2 (only) set to frequency 128.615 MHz.

TEST NO. 5 LOG

Adjacent Channel Breakthrough Effect on Bearing Readout (CW Mode)

Wanted Signal (Tx No. 1): 50 µV/m, 0° Azimuth

Unwanted Signal (Tx No. 2): 1.5 mV/m, 90° Azimuth

WANTED SIGNAL FREQ. MHz Tx No. 1	UNWANTED SIGNAL FREQ. MHz Tx No. 2	BEARING READOUT (Degrees)		BEARING CHANGE (Degrees)
		Min.	Max.	Max.
128.600	OFF	____	____	____
128.600	128.625	____	____	____
128.600	128.620	____	____	____
128.600	128.615	____	____	____

4.6 TEST NO. 6 - EFFECT OF TWO TEST SIGNALS RECEIVED IN THE SAME CHANNEL AND ANGULARLY DISPLACED BY 90° (CW MODE)

4.6.1 Specification Limit

(a) **Purpose of Test**

This test is intended to record the effect produced on the BEARING display readout when two test signals of identical frequency and variable field strengths are received in one selected channel. The information obtained is to be recorded in the appropriate spaces of TEST NO. 6 LOG SHEET.

(b) The bearing reading shall not change by more than ±3° for interfering signal level of 10 dB below wanted signal level, and originating at 90° relative to wanted signal.

NOTE: This measurement is dependent upon the frequency and phase difference of the two signals, hence the accuracy of the tests limited.

4.6.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(2)
Item 2	RF Power Amplifier	(1)
Item 3	Test Dipole	(2)
Item 4	Tripod	(2)
Item 5	Power Generator Pack	(2)
Item 6	Field Strength Meter	(1)

4.6.3 Test Procedure

NOTE: Figure 2 is a pictorial view (overhead) of the general test set-up.

(a) Set up one test dipole (No. 1) on the calibration circle at any selected array angle. (e.g. at 0° ref. point).

(b) Set up the other test dipole (No. 2) on the circle at a position angularly displaced from dipole No. 1 by 270° in a clockwise direction (overhead view).

(c) Connect test transmitter No. 1 to test dipole No. 1 and to its power pack. **DO NOT** switch on this transmitter until it is required.

(d) Connect test transmitter No. 2 to test dipole No. 2 and to its power pack. **DO NOT** switch on this transmitter until it is required.

(e) Ensure that the test transmitter and auxiliary equipment are positioned behind the test dipoles and outermost from the calibration circle.

(f) Set the antenna turntable to position zero reference.

(g) On test transmitter No. 1, select test frequency 128.600 MHz and modulation mode CW. Select DF system frequency 128.600 MHz.

(h) Set test transmitter No. 1 output level to obtain 50 uV/m field strength. This output is to remain constant throughout the test.

(i) Record the BEARING display readout on TEST NO. 6 LOG SHEET.

(j) On test transmitter No. 2, select test frequency 128.600 MHz and modulation mode CW.

(k) Set test transmitter No. 2 output level to obtain 16.6 uV/m reading on the field strength meter. (NOTE: after Tx set-up, remove FSM from testing area).

(l) Repeat step (i) above.

(m) Repeat steps (k) and (i) with the test transmitter No. 2 output level adjusted in steps of 2 dB above and below the test transmitter No. 1 level, and note the levels at which the bearing reading changes over and also when blanking occurs.

TEST NO. 6 LOG

Effect of Two Test Signals Received in the Same Channel and Angularly Displaced by 90° (CW Mode)

Transmitter No. 1: 0° Azimuth, Frequency 128.600

Transmitter No. 2: 90° Azimuth, Frequency 128.600

Tx NO. 1 LEVEL µV/m	Tx No. 2 LEVEL dB	BEARING READOUT (Degrees)	BEARING CHANGE (Degrees)	REMARKS
50	OFF	______ (Ref.)	0	
50	-8 dB	______	______	
50	-6 dB	______	______	
50	-4 dB	______	______	
50	-2 dB	______	______	
50	0 dB	______	______	
50	+2 dB	______	______	
50	+4 dB	______	______	
50	+6 dB	______	______	
50	+8 dB	______	______	
50	+10 dB	______	______	

4.7 TEST NO. 7 - BEARING READOUT CHANGE FOR HIGH ANGLE ELEVATION WITH OVERHEAD-PASS INDICATION

4.7.1 Specification Limits

The DF system OVERHEAD PASS light should start flashing with the elevation angle limits of 60 ±5°. Owing to difficulties in making measurements with a moving plane, this performance will be simulated by moving the test dipole towards the tower, to establish a relative performance of the system.

4.7.2 Test Equipment (Section 3.0)

Item 1	Test Transmitter	(1)
Item 3	Test Dipole	
Item 4	Tripod	(1)
Item 5	Power Generator Pack	(1)
Item 8	Oscilloscope	(1)

4.7.3 Test Procedure

(a) Set test dipole and transmitter at position zero reference on the calibration circle.

(b) Set test frequency to 128.600 MHz and signal level 50 µV/m field strength.

(c) Set antenna turntable to zero position.

(d) Connect oscilloscope to output of phase detector and trigger from North Reference test point. Observe the phase detector waveform and peak-to-peak amplitude.

(e) Obtain bearing readout and peak-to-peak amplitude voltage.

(f) Move the test dipole and test transmitter towards the tower to a distance of 33 ft. from the tower centre line.

(g) Observe the amplitude of the phase detector waveform and record peak-to-peak voltage. Also record the bearing readout.

(h) Repeat (f) and (g) for distances of 23, 20, 19, 18 and 15 ft.

(i) From the readings of phase detector amplitude, calculate the elevation angle and compare to the physical angle given in the Log Table. At the same time, note the overhead light. It should be on at 60° ±5%.

TEST NO. 7 LOG

Bearing Reading Change for High-Angle Elevation with Overhead Pass Indication

Text Tx: 0° Azimuth, 128.600 MHz, 50 µV/m

TEST Tx DISTANCE (h) (d)	PHASE DETECTOR P-P Amplitude	COMPUTED ELEV. ANGLE (Deg.)		BEARING (Degrees)	O/H LIGHT
		PHYSICAL**	ELECTRICAL***		
150'	______ (Ref.)	12.4	______	______ (Ref.)	OFF
33'	______	45	______	______	
23	______	55	______	______	
20	______	59	______	______	
19	______	60	______	______	
18	______	61	______	______	
15	______	65	______	______	

d = Distance between DF antenna and Test Tx

h = Height of DF Antenna above Test Tx Antenna = 33 ft.

** = Elevation Angle = $\tan^{-1} \frac{h}{d}$

*** = Elevation Angle = $\cos^{-1} \left(\frac{\text{P-P Amplitude Step (g)}}{\text{P-P Amplitude Step (e)}} \right)$

5.0 PERFORMANCE CHARACTERISTICS

5.1 Frequency Range : 117.5-136.5 MHz

5.2 Principle of Operation : Large aperture Quasi-Doppler with differential sampling of 16 antenna elements.

5.3 Equipment Accuracy : ±1,5° (target ±1.0°) measured with antenna simulator.

5.4 System Accuracy (Installed) : ±3° with 16 element antenna

5.5 Polarization Error : 2° max. with 45° tilt of Tx antenna

5.6 Sensitivity (vertical polarization) : ≤5 uV/m for ±1° of noise flicker

5.7 Group Delay Error : Cancelled out by digital processing

5.8 DF Receiver Phase Match Error : Cancelled out by Bearing Processor

5.9 Mode Operation : Continuous, unattended

5.10 Number of Frequency Channels : Emergency channel plus 10 switch-selected - each channel frequency programmable within the equipment and full range of 720 channels, operator selectable by push-button dialing.

5.11 Channel Spacing : 25 kHz

5.12 Acceptance Bandwidth : ±7.5 kHz

5.13 Adjacent Channel Breakthrough : ≤1° error with adjacent channel signal up to 30 dB above wanted signal but not exceeding 30 mV/m.

5.14 Bearing Indication : 4 digits with LED numerals blanking out at no signal unless connected to store: display at both local and remote units. Analog display circle of LED's in 5° steps at Operator's Panel only.

5.15 Response Time : 0.2 sec. to 0.8 sec., depending on the signal strength.

5.16 Bearing Readout Update : Equal to integration constant.

5.17 Valid Display Indicator : Inaccurate bearings fluctuating by more than ±10° are blanked out.

5.18 Operator Panel Controls : Power On/Off; Dimmer (bearing and channel display only); Lamp test; Channel select (illum. push-button); QDM/QDR; Store On/Off with indicator; Remote control indicator; System alarm indicator; Signal overhead indicator; Frequency select mode and reset.

5.19 Receiver Panel Controls : As above, except no store On/Off and indicator; Squelch On/Off; Synthesizer phase lock indicator.

5.20 Auxiliary Data Output : At both local and remote units, TTL compatible parallel data bit format.

5.21 Auxiliary Channel Select : At the remote unit for control from another site.

5.22 Squelch Threshold : Fully adjustable from front panel of remote.

5.23 Service Telephone : Jacks provided for 2-way communication between remote and local units (audio channel disabled).

5.24 Aircraft Warning Light : Integrated with antenna structure (may be left out if not required).

Audio Monitoring Facilities

5.25 Omni-directional Antenna : Centre of the Array

5.26 Frequency : Automatically tuned with the DF System.

5.27 Type of Detector : AM

5.28 Output : 0.5W loudspeakers on both remote and local units.

5.29 Auxiliary Output : 50 mV at 600 Ohms on the local unit.

5.30 Squelch : Provided on Remote Unit

5.31 AGC : Provided on Remote Unit

5.32 Volume Control : Individual with each loudspeaker

Emergency Receiver Facility

5.33 Antenna : Common with audio monitoring provided with separator filter

5.34 Tuning : Set at 121.5 MHz

5.35 AGC : Pre-set

5.36 Detector : Carrier presence above threshold pre-set at the Remote Unit

Additional Controls

5.37 Auto/Man. : At both local and remote units.

5.38 Alarm : LED indicators at local and remote units

APPENDIX 5

FIELD TEST DEMONSTRATION

SEPTEMBER 1983

TABLE OF CONTENTS

GENERAL

Test No. 1 System DF Sensitivity

Test No. 2 Effect of Controlled Variations in Signal Operating Conditions

Test No. 3.1 DF System Accuracy (by antenna rotation)

Test No. 3.2 DF Accuracy - Target Rotation (including field site effects)

Test No. 4 Bearing Readout Change with Angle of Polarization

Test No. 5 Adjacent Channel Breakthrough

Test No. 6 Effect of two test signals in the same channel

Test No. 7 Overhead Pass Indication

FIELD TEST DEMONSTRATION

VHF QUASI-DOPPLER DF SYSTEM

PRODUCTION PROTOTYPE

NOTE:

This demonstration of the VHF/DF System was scheduled at the end of a rush assembly period which was performed in a record time of two months. However, some delays were experienced with deliveries of the component parts, which consequently reduced the time available for in-plant testing. As a result, some software errors have shown up in the field test which normally would not have been allowed. The necessary correction of the software is in process and the test will be repeated in all areas affected by the changes. In light of this occurrence, the attached test results are viewed by neglecting the readings affected by the software fault.

DATE OF DEMONSTRATION: September 7, 8, 9, 1983

ATTENDANCE:

Bayly Engineering:	R. Menkal (part-time) Z.A. Krajewski F. Baehr W. Ng (part-time) J. McKay
Transport Canada (Ottawa):	W. Tweedie
TDC (Montreal:	M. Avni (part-time)

TEST PROCEDURES

'System Field Performance Test Plan and Performance Characteristics' dated August 1983 (Bayly Engineering).

TEST RESULTS AND COMMENTS

Results of the tests are presented in the LOG sheets of the procedures, except for the DF accuracy, where a graphical display was preferred. Relative comments are added at the end of each test.

NOTE OF THANKS

Thanks are due to Transport Canada for the loan of a field strength meter, without which this test would not have been possible on the given date, since the Company's equipment had to be sent out for repairs.

TEST NO. 1 LOG

System DF Sensitivity (CW Mode)

NOTE:	Freq.	Sig. Gen. Set	Field Strength
	133 MHz	-38 dBm	5.2 µV/m
	118.25 MHz	-38 dBm	3.5 µV/m

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		BEARING SPREAD (Degrees)
	Min.	Max.	
118.250	0.9	1.2	0.3
128.600	0.3	0.8	0.5
133.000	1.8	2.3	0.5

Spec. Limit: Bearing Spread 3° max. for signal strength 5 µV/m

COMMENTS:

DF sensitivity results exceptionally good (bearing spreads 0.5° or better).

TEST NO. 2 LOG

Effect of Controlled Variations in Signal Operating Conditions

All tests at a signal field strength of 30 µV/m

1. FREQUENCY DETUNING (CW MODE)

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
	Min.	Max.		
128.600	359.8	359.9	359.85 (Ref.)	-
128.603	359.4	359.8	359.6	-0.25
128.606	358.8	359.9	359.85	0.0
128.597	359.6	359.8	359.7	-0.15
128.594	359.5	359.6	359.55	-0.3

2. AMPLITUDE MODULATION (AM MODE) - 30% AT 1 kHz

TEST FREQUENCY (MHz)	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
	Min.	Max.		
128.600 (CW Mode)	359.8	359.9	359.85 (Ref.)	-
128.600 (AM 30%)	0.0	0.3	0.15	+0.3
128.606 (AM 30%)	359.6	0.6	0.1	+0.25
128.594 (AM 30%)	359.9	0.3	0.1	+0.25

COMMENTS:

Effects of both detuning and modulation fully acceptable within the specified bandwidth of ±7.5 kHz.

3. SIGNAL STRENGTH (CW MODE, 128.6 MHz FREQUENCY)

SIGNAL GEN. SETTING	TEST SIGNAL STRENGTH	BEARING READING (Degrees)		READING AVERAGE (Degrees)	± CHANGE (Degrees) (from Ref.)
		Min.	Max.		
-40 dBm	8.5 µV/m	359.8	0.7	0.25	+0.3
-34 dBm	5 µV/m	0.2	0.4	0.3	+0.35
-28 dBm	10 µV/m	0.2	0.2	0.2	+0.25
-14 dBm	50 µV/m	359.8	0.1	359.95	0.0 (Ref.)
-8 dBm	100 µV/m	0.0	0.1	0.05	+0.1
+2 dBm	300 µV/m	359.8	359.8	359.8	-0.15
+12 dBm	1 mV/m	359.7	359.8	359.75	-0.2
+22 dBm	3 mV/m	0.1	0.2	0.15	+0.2
+32 dBm (with amplifier)	10 mV/m	0.1	0.2	0.15	+0.2

RESULTS:

Bearing readings are plotted against field strength on the attached graph of Fig. 1.

COMMENTS:

Change of average reading 0.35° or better over a dynamic range of 72 dB.

KEUFFEL & ESSER CO., N. Y. NO. [redacted]

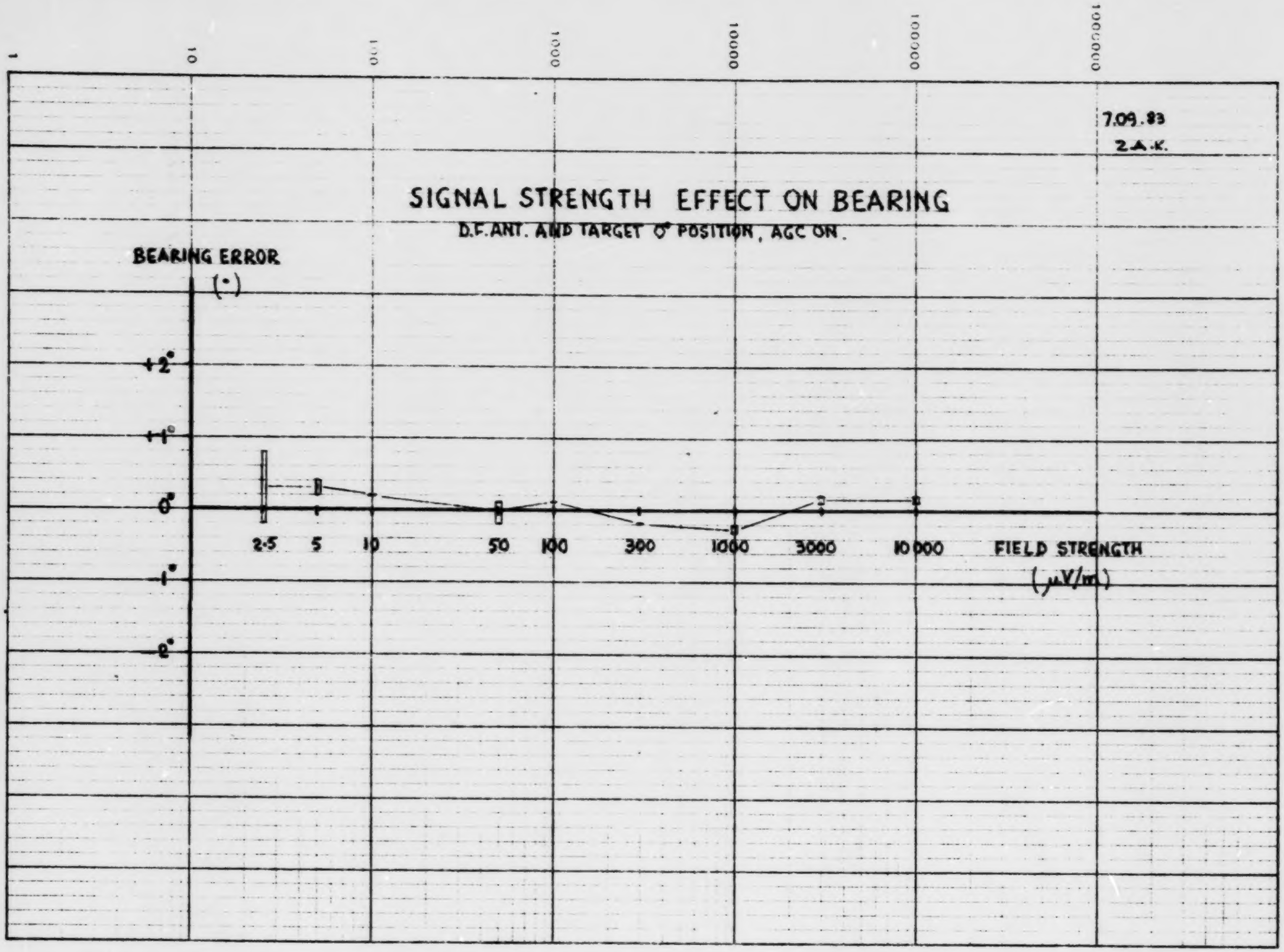


FIGURE 1

TEST NO. 3.1

DF SYSTEM ACCURACY

SCOPE

This test is intended to verify the DF accuracy of the system as installed, but without the effects of the field (ideal site). For this purpose, the DF antenna is rotated on top of the mast and the transmitting target is set at a fixed location of 0° (North). The field site errors are thus eliminated except for a possible constant offset of the target position.

TEST RESULTS

Bearing readings were taken at three frequencies (118.25 MHz, 128.6 MHz and 133.0 MHz) and at three field strength levels (5 µV/m, 50 µV/m and 1 µV/m) for each of the 16 angles of the antenna rotation, i.e. every 22.5 degrees. At one of the test frequencies (118.25 MHz) readings were taken in steps of 11.25 degrees, totalling 32 antenna positions. Bearing errors were calculated as compared with the mechanical angle settings. The results are plotted against the angle of antenna rotation in nine separate graphs (Fig. 2 through 10), each set of three corresponding to a given level of field strength.

COMMENTS

The majority of results show a usual pattern of variation of bearing error of approximately ±3° which can be expected before the application of the built-in calibration corrections. The exceptions are readings at 247.5° angle of rotation plus a couple of points at 292.5°. Bearings taken in these positions show 'wild' errors of 7° - 15°, quite inconsistent with the rest of the pattern. A subsequent investigation has shown this to be a mistake in the software program of the bearing processor, which was not detected in the in-plant testing using the antenna simulator. The program will be modified and a new set of readings will be taken to show the correct performance.

DF SYSTEM ACCURACY, F.S 5 µV/m

BEFORE CORRECTION

TARGET AT 0° AZIMUTH, DF ANTENNA ROTATED

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Z.A.K

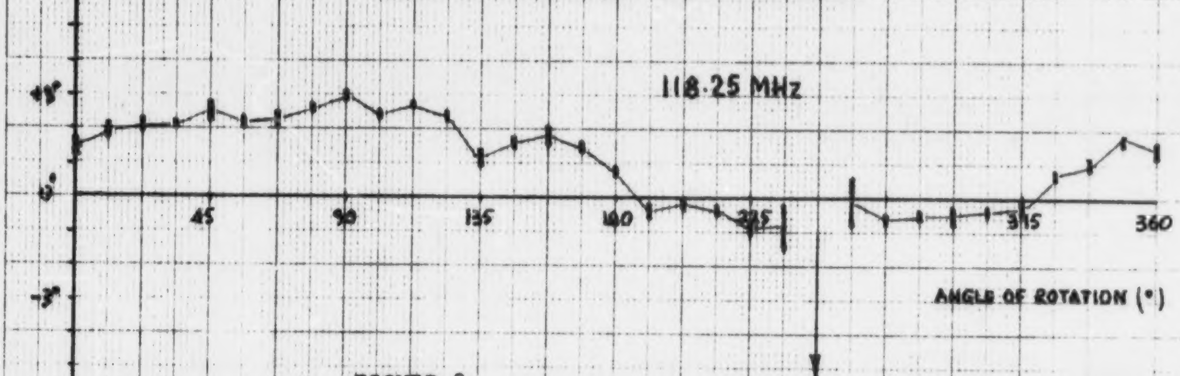

FIGURE 2

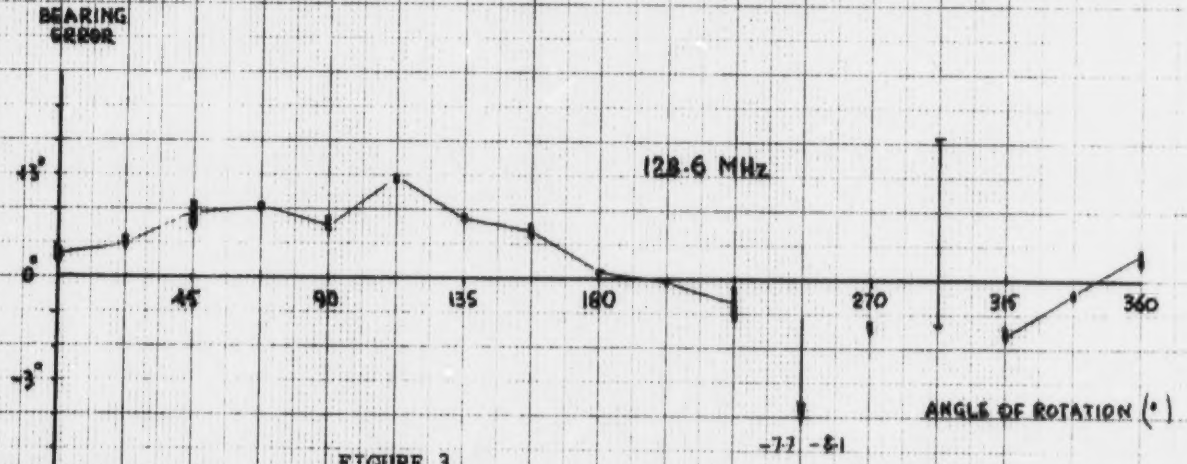

FIGURE 3

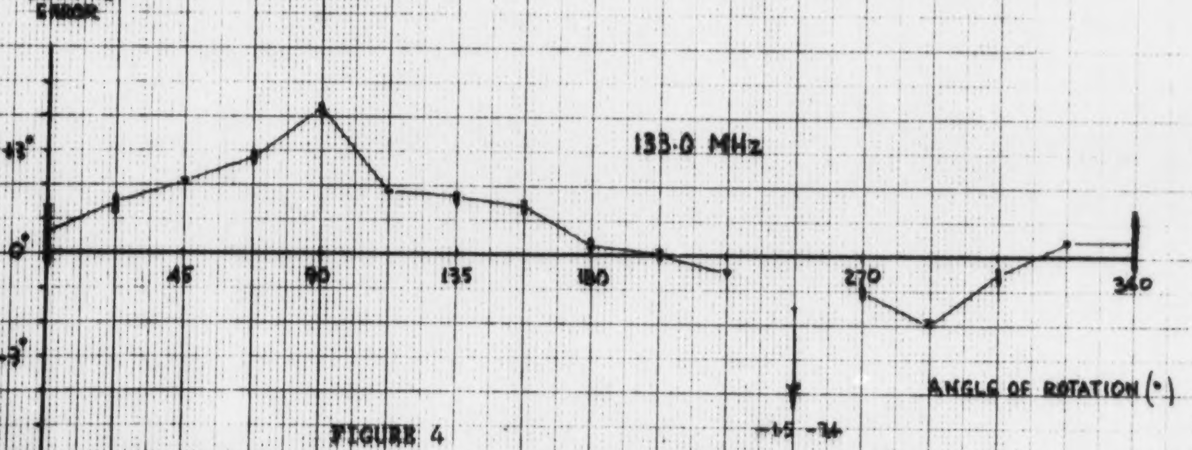

FIGURE 4

D.F. SYSTEM ACCURACY, FS 50 µV/m

BEFORE CORRECTION

TARGET AT 0° AZIMUTH, DF ANTENNA ROTATED

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Z.A.K.

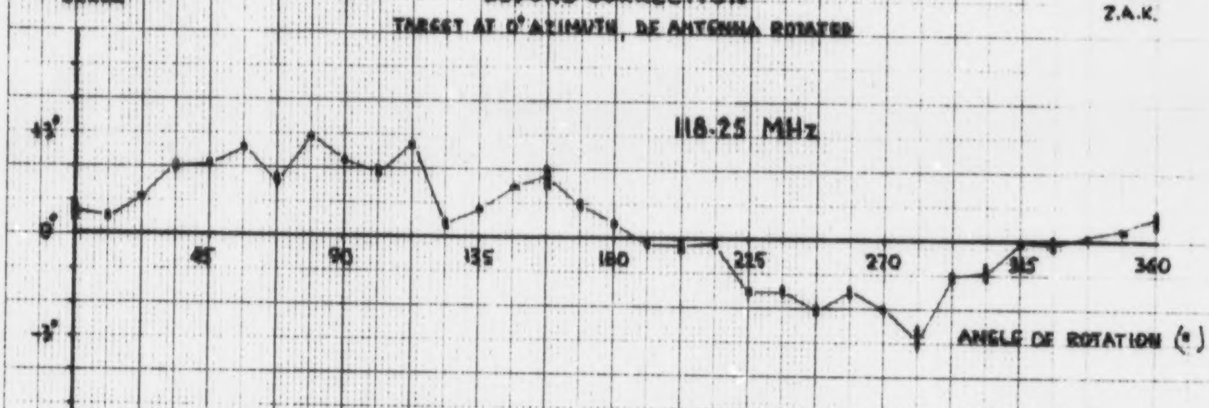

FIGURE 5

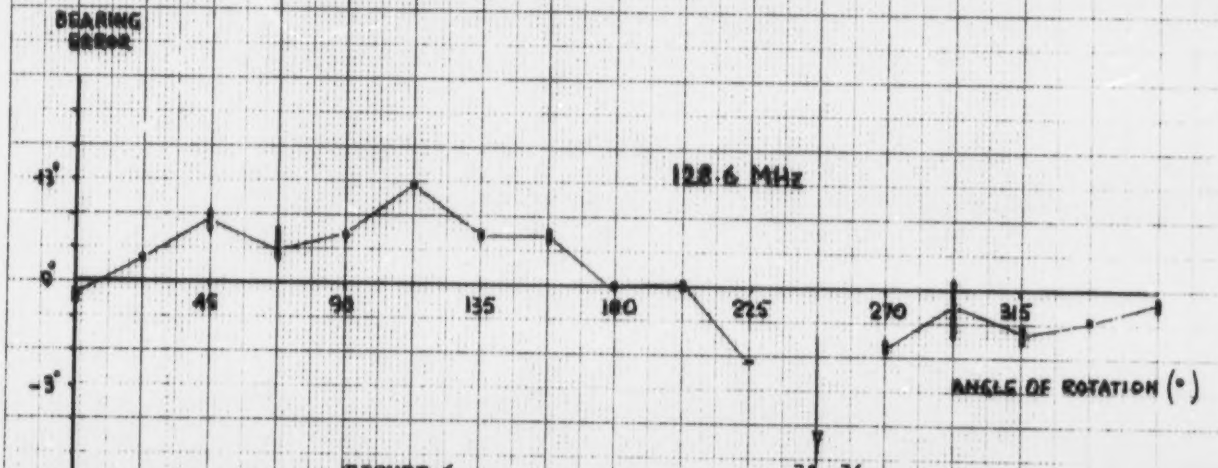

FIGURE 6

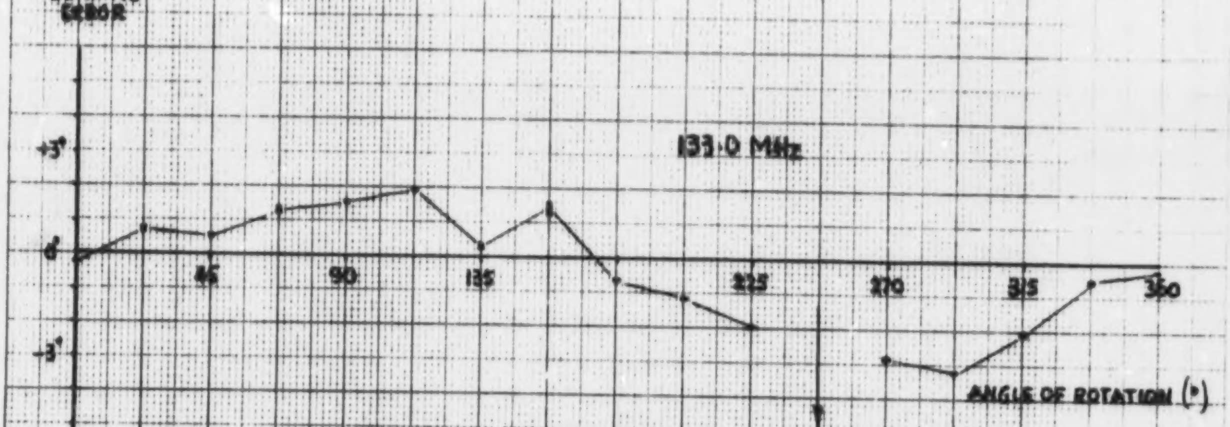

FIGURE 7

D.F SYSTEM ACCURACY, F.S. 1 mV/m

BEFORE CORRECTION

TARGET AT 0° AZIMUTH, D.F. ANTENNA ROTATED

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Z.A.K.

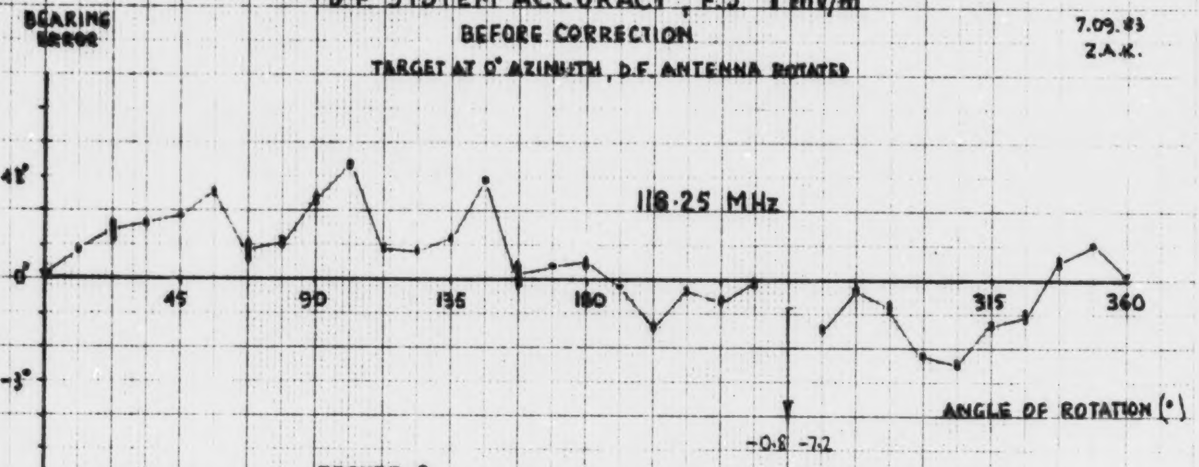

FIGURE 8

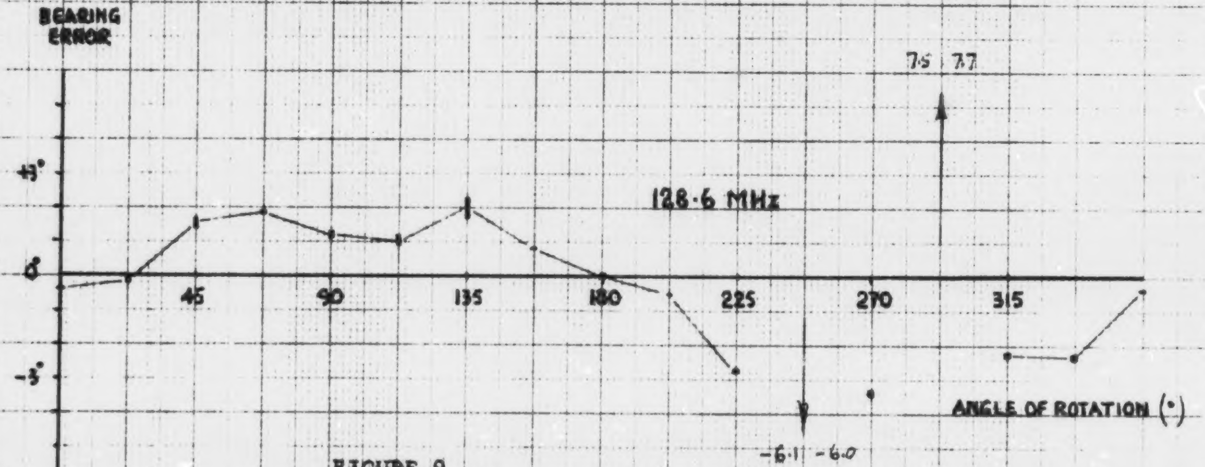

FIGURE 9

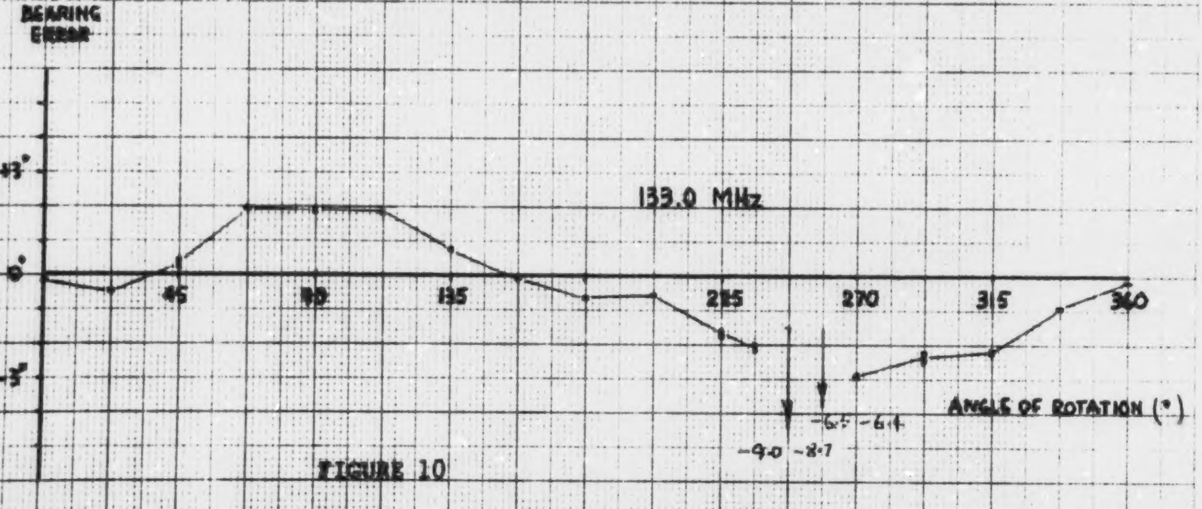

FIGURE 10

CALIBRATION

Neglecting the 'wild' angle readings the bearing error graphs of Fig. 2 through 10 were used to prepare a chart of calibration corrections for insertion into the 2nd microprocessor of the bearing processor sub-system. The corrections were taken every 5 degrees of the angle of rotation, using the average sine-wave patterns drawn through the bearing error graphs obtained for antenna rotation. The 50 uV/m field strength level was taken as the reference. The resulting calibration correction curves are shown in Figs. 11-13.

The intention of the demonstration was to show the DF accuracy graphs before correction and then to program the software with the corrections so as to be able to repeat the DF accuracy measurements with the corrections applied. Unfortunately, time was running short, so it was decided to carry on with the outstanding tests 3B through 7.

A set of corrected figures for antenna rotation was computed instead from the data of Fig. 2 for the field strength level of 50 uV/m. The results are shown in Figs. 4-16, indicating a reduction of the instrumental bearing errors to ±1.5 degrees or less which was the objective of the target specification.

D.F. SYSTEM ACCURACY

ERROR AVERAGES

USED FOR CALIBRATION CORRECTION

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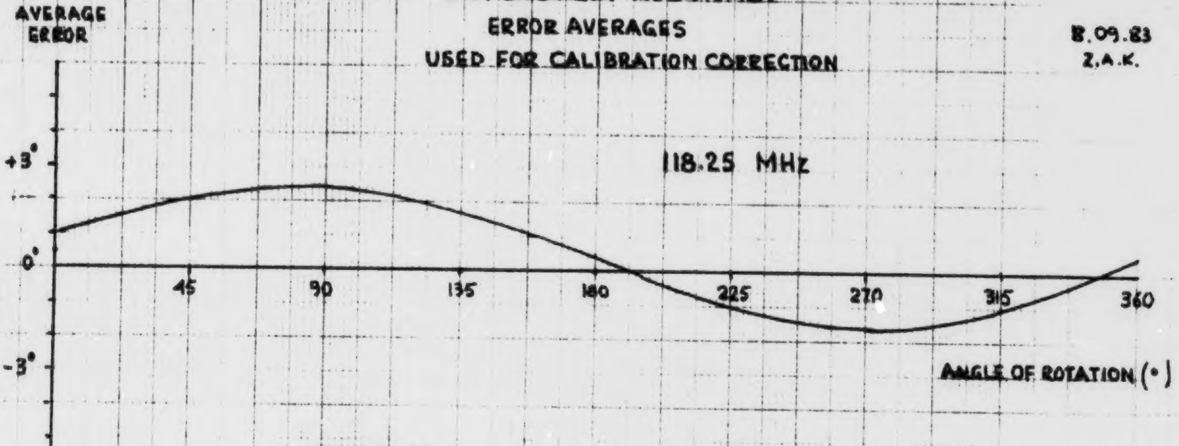

FIGURE 11

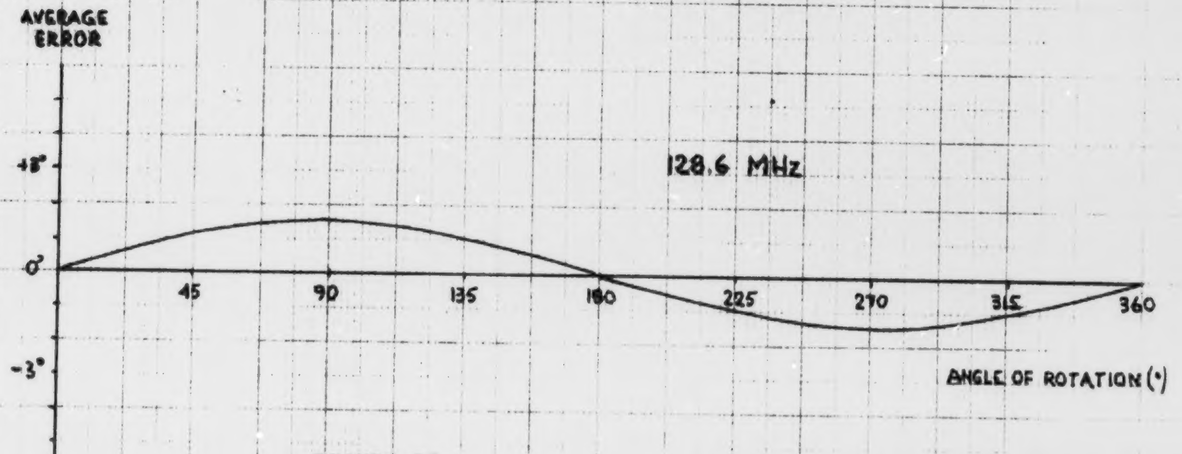

FIGURE 12

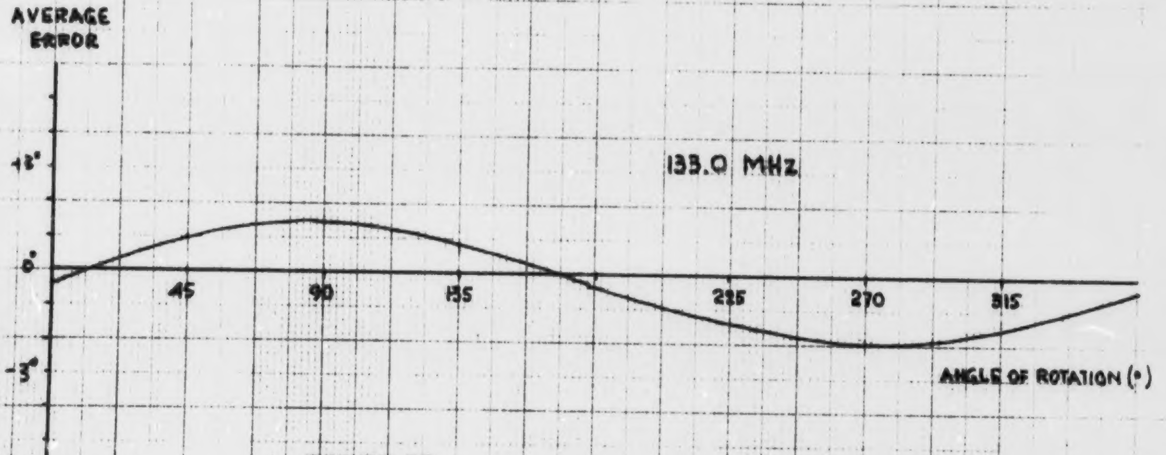

FIGURE 13

D.F. SYSTEM ACCURACY , F.S. 50 µV/m
CALIBR. CORRECTION APPLIED
(TARGET AT 0° AZIMUTH , DF. ANTENNA ROTATED)

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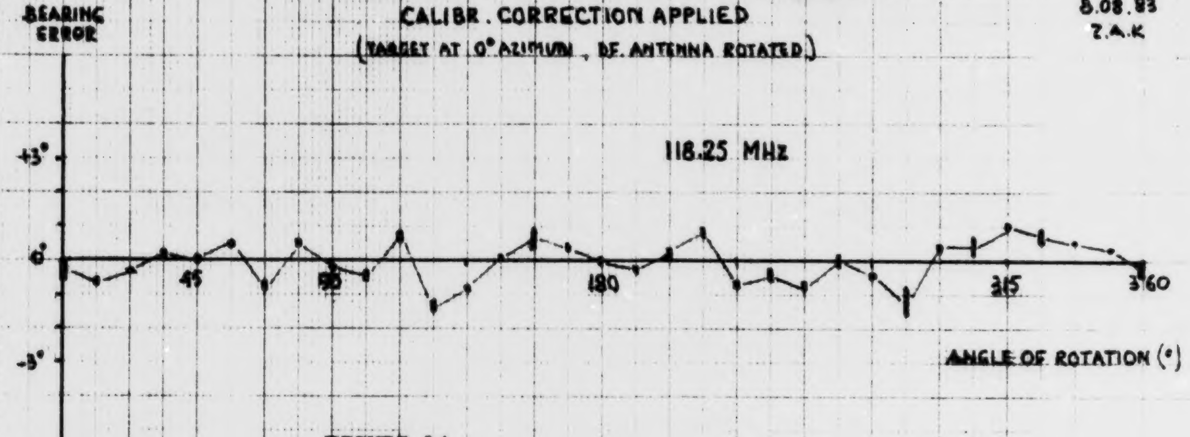

FIGURE 14

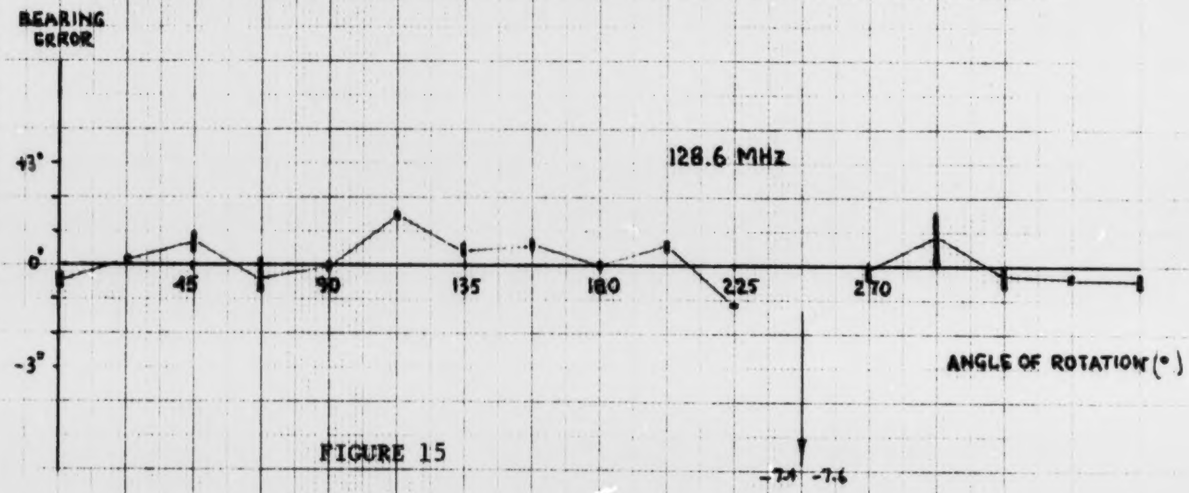

FIGURE 15

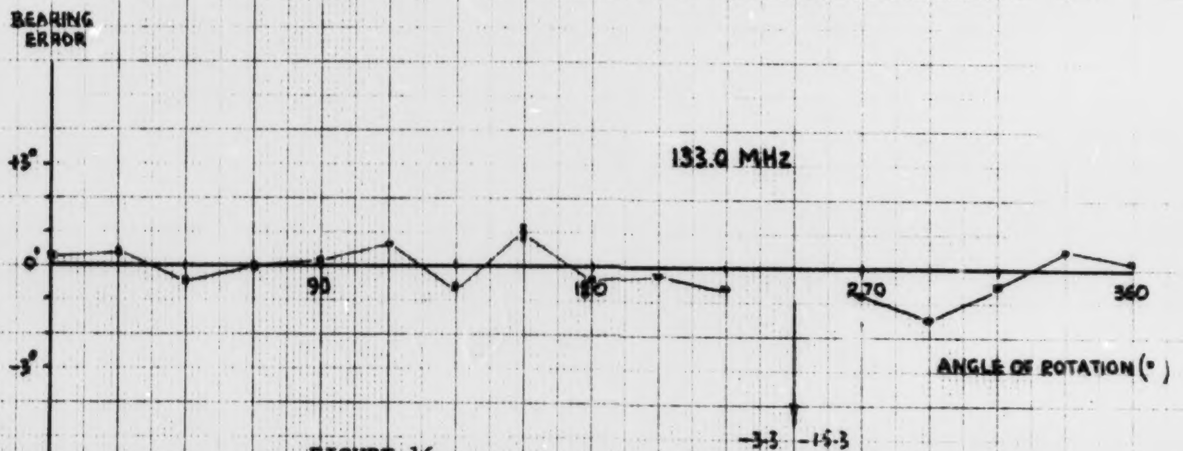

FIGURE 16

TEST NO. 3.2

DF INSTALLATION ACCURACY INCLUDING FIELD EFFECTS

SCOPE

The purpose of this test is to demonstrate the accuracy of the DF system, as installed at the site, for use of indicating the directions of the aircraft in radio contact with the control tower. The DF antenna is firmly set in the 0° azimuth or North position and a target transmitter is carried around the calibration circle. Bearing errors obtained by this method present a combination of the instrumental system errors and the field site errors.

MEASUREMENTS BEFORE CALIBRATION CORRECTION

A set of bearing readings was taken with the DF antenna in 0° position and the target transmitter set in steps of 22.5° on the perimeter of the 60 m calibration circle. The readings were obtained for the same three frequencies (118.25 MHz, 128.6 MHz and 133.0 MHz) and for the same field strength levels (5 μV/m, 50 μV/m and 1 mV/m) as in the tests with antenna rotation. The results were plotted in graphs in Fig. 17-25. A set of 3 is given for each level of signal strengths.

MEASUREMENTS WITH CALIBRATION CORRECTIONS

At this point, the microprocessor PROM was replaced with one programmed for the calibration corrections. The target transmitter was taken around the DF site once again, and a new set of readings was obtained showing the DF installation accuracy with the built-in correction program. The results of this final test are shown graphically in Fig. 26-34.

D.F ACCURACY - TARGET ROTATION, F.S. 5 μV/m

D.F. ANT. 0° POSITION, NO CALIBR. CORRECTION

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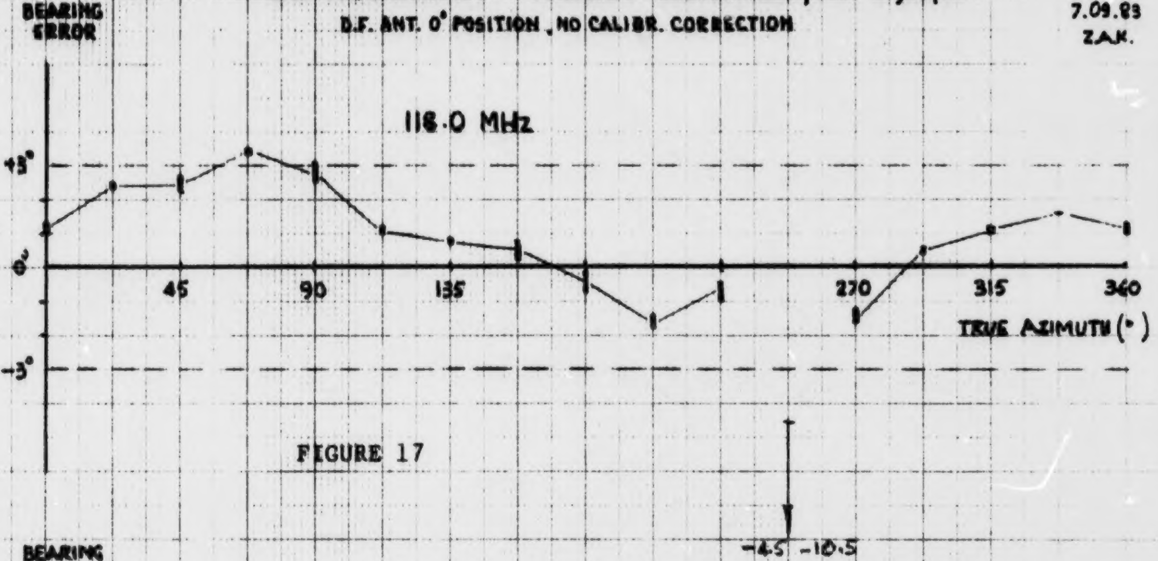

FIGURE 17

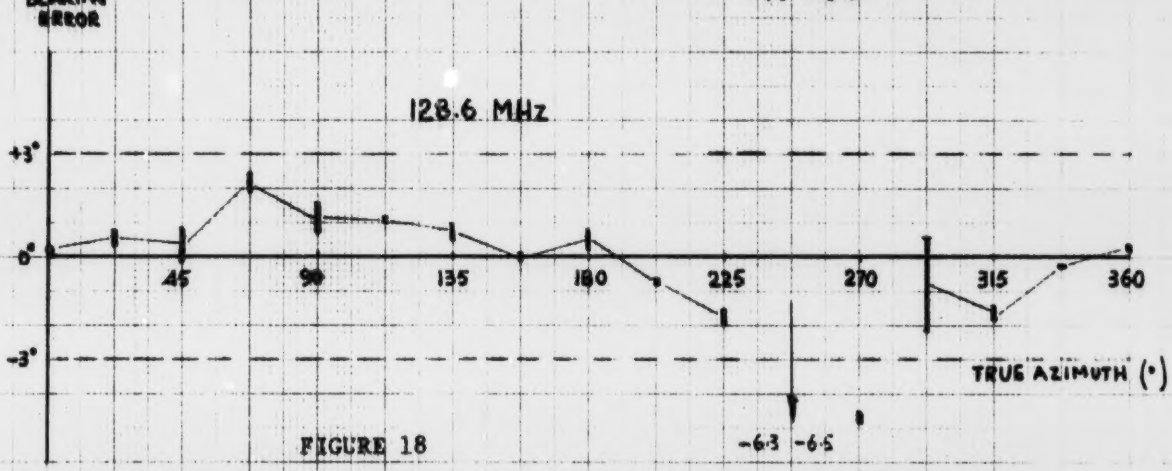

FIGURE 18

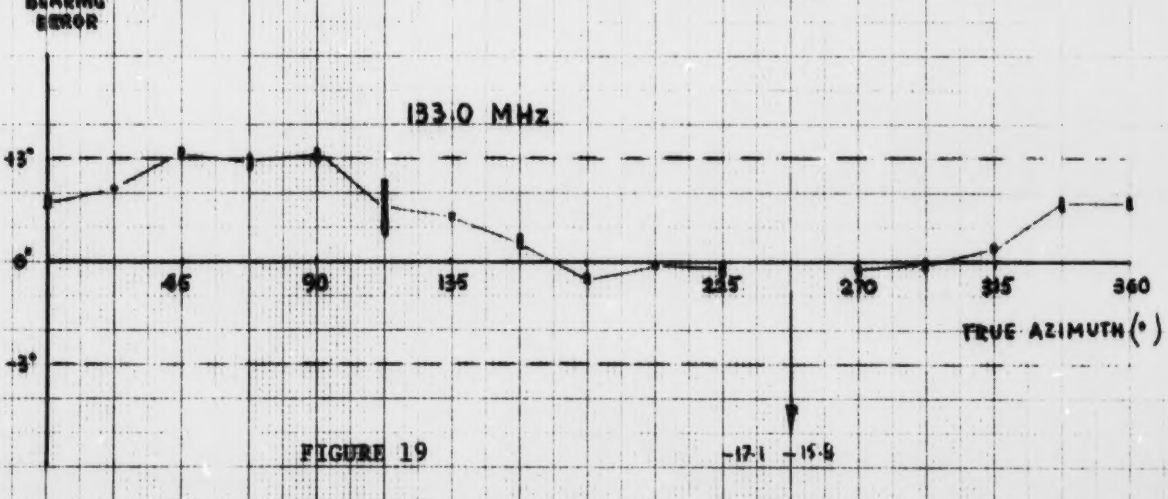

FIGURE 19

46 1513

DF ACCURACY - TARGET ROTATION, F.S. 50 µV/m

D.F. ANT. 0° POSITION, NO CALIBR. CORRECTION

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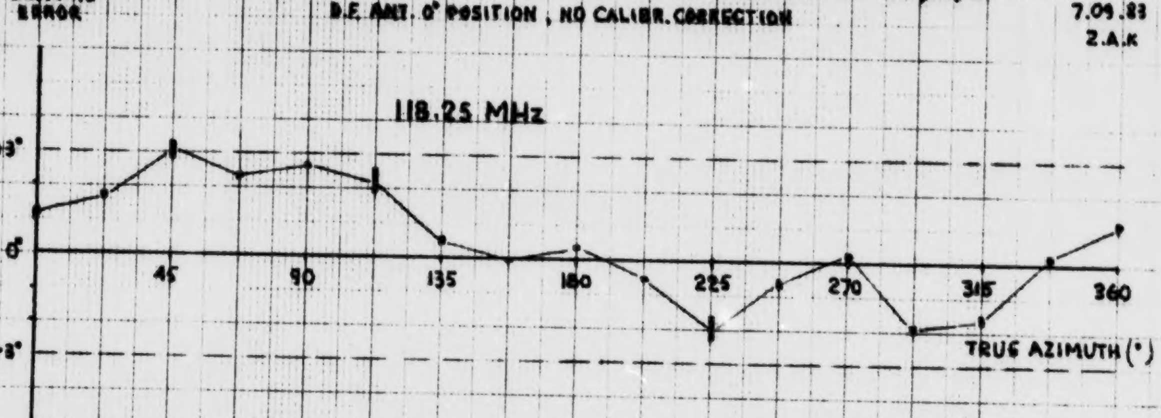

FIGURE 20

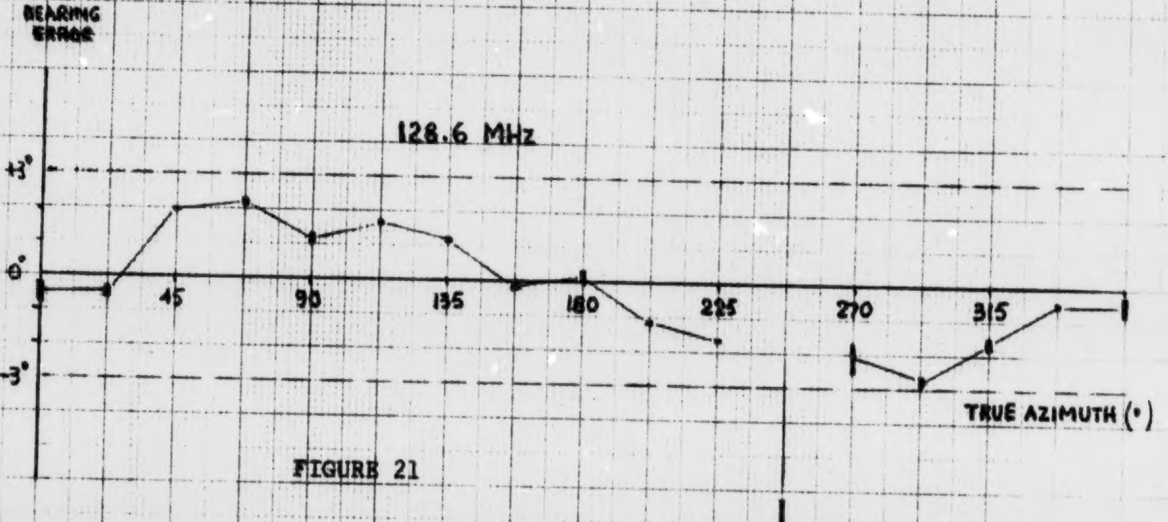

FIGURE 21

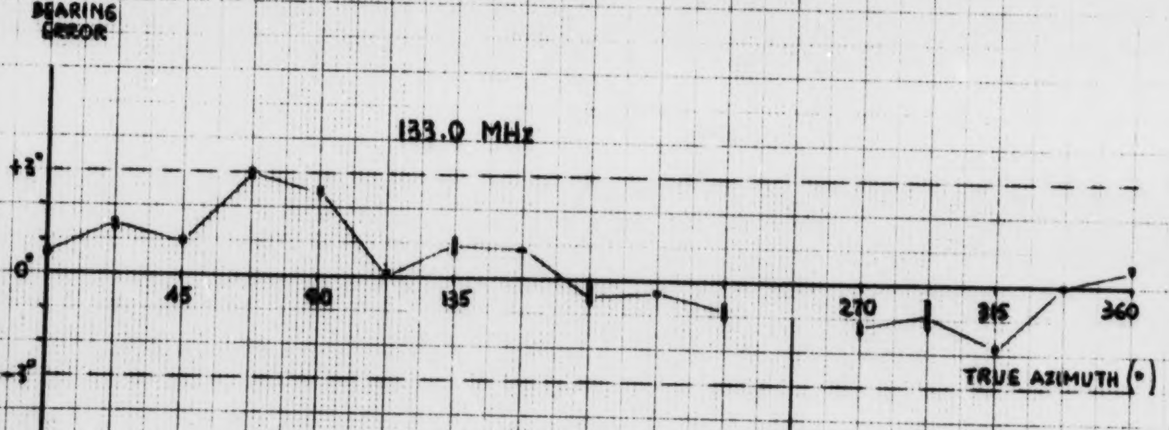

FIGURE 22

D.F. ACCURACY - TARGET ROTATION, F.S. 1 mV/m

D.F. ANT. 0° POSITION, NO CALIBR. CORRECTION

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Z.A.K.

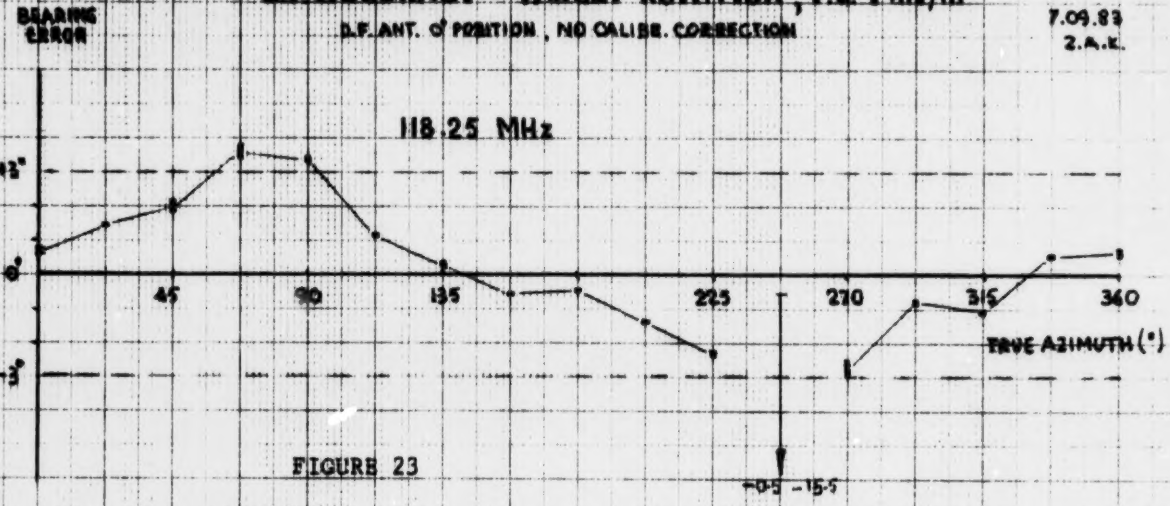

FIGURE 23

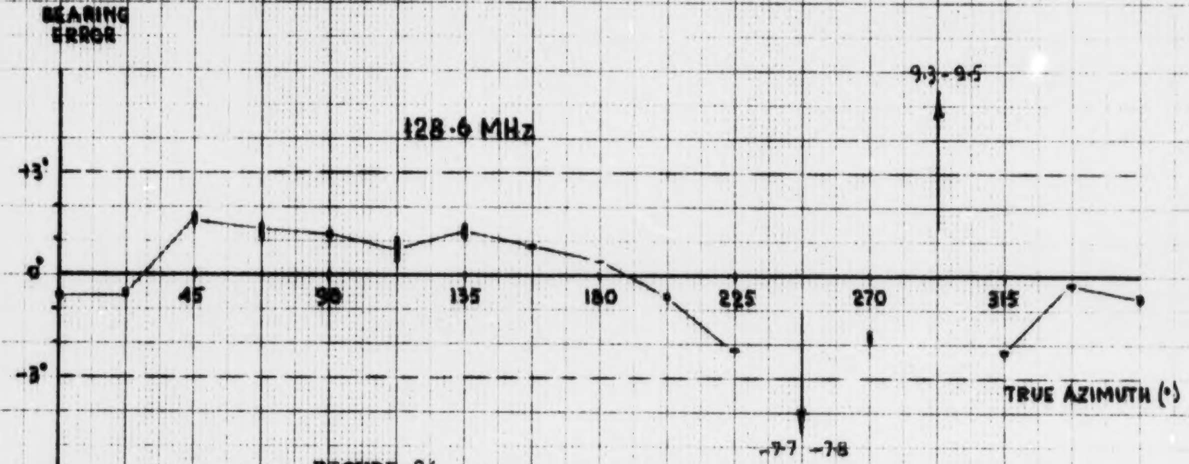

FIGURE 24

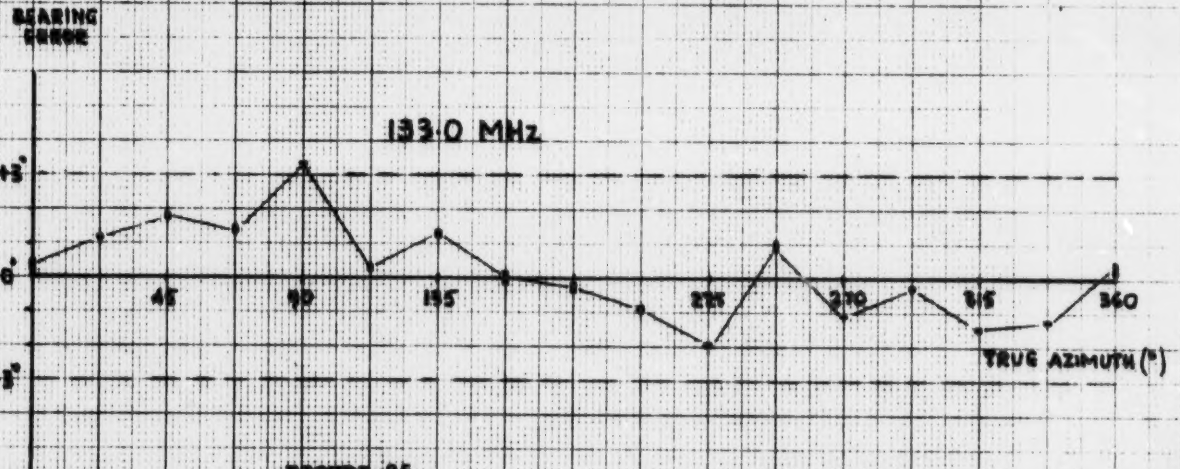

FIGURE 25

46 1513
KEUFFEL & ESSER CO.

D.F. ACCURACY – TARGET ROTATION, F.S. 5 μV/m

D.F. ANT. 0° POSITION, SYST. CALIBR. CORR. APPLIED

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Z.A.K.

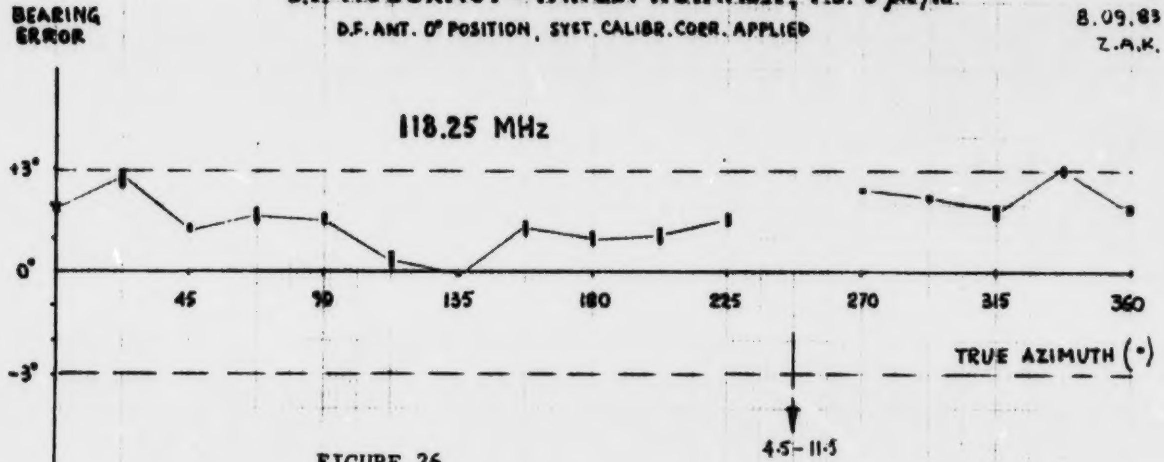

FIGURE 26

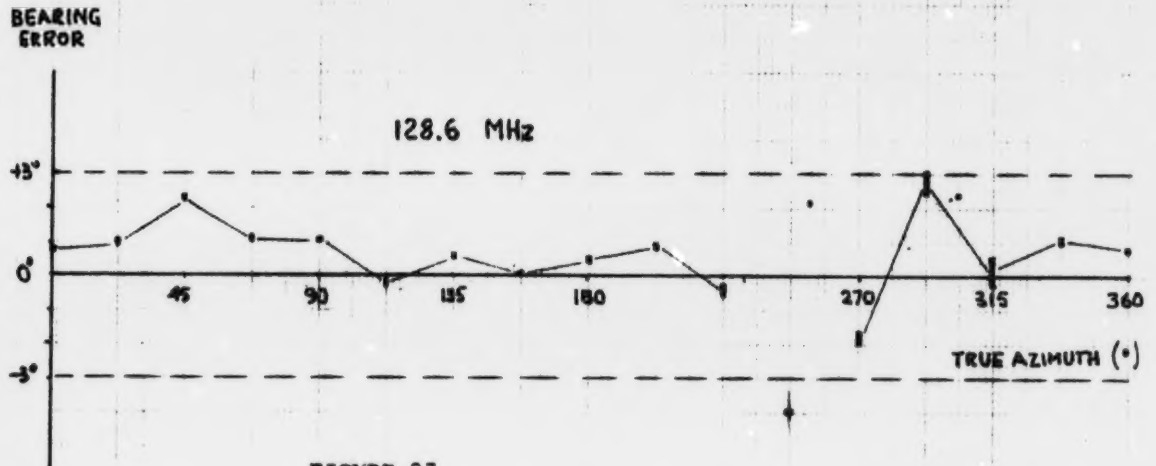

FIGURE 27

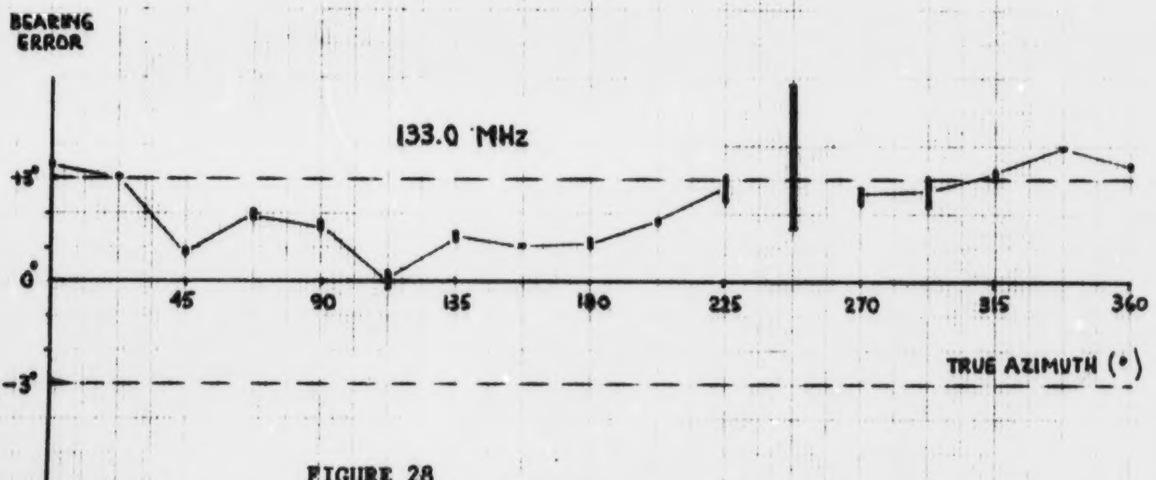

FIGURE 28

D.F. ACCURACY – TARGET ROTATION, F.S. 50 µV/m

D.F. ANT. 0° POSITION, SYST. CALIBR. CORR. APPLIED

8.09.83
Z.A.K.

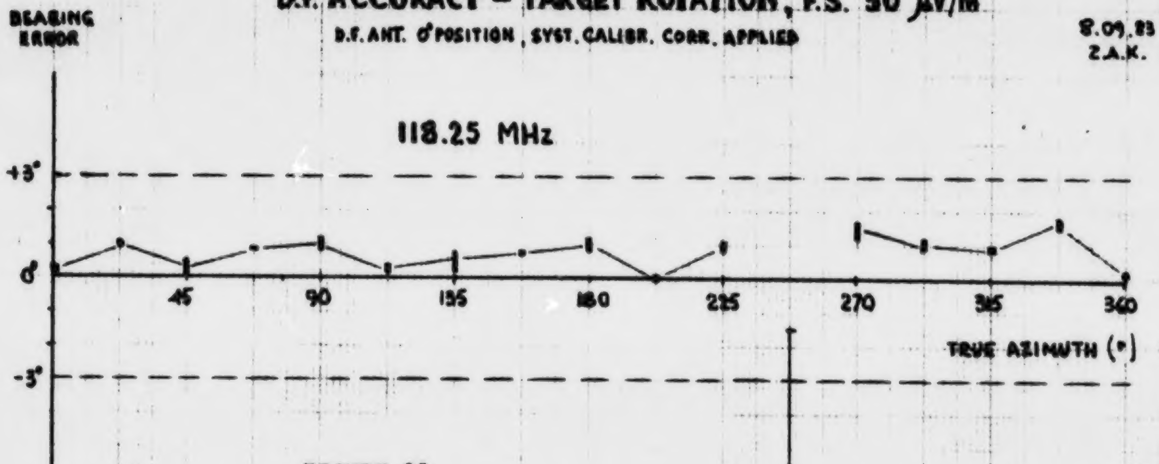

FIGURE 29

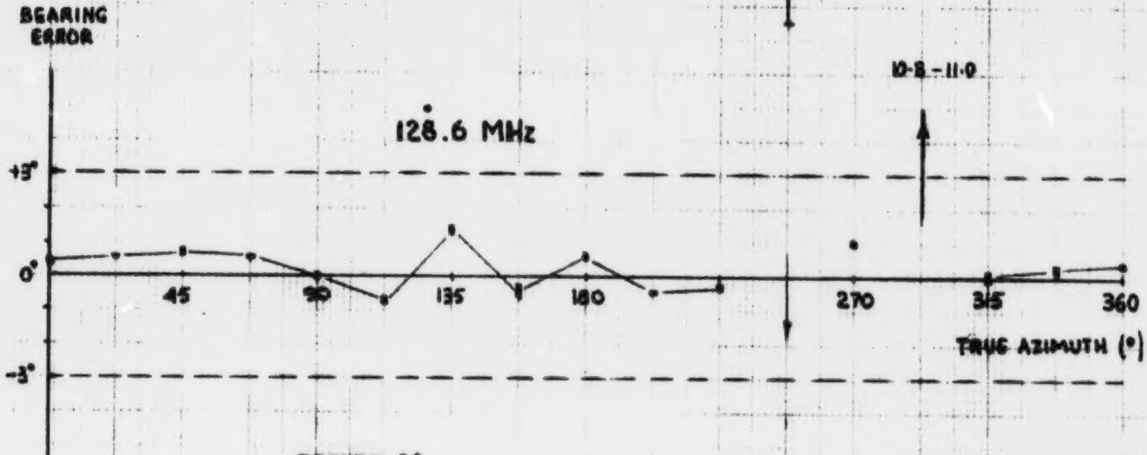

FIGURE 30

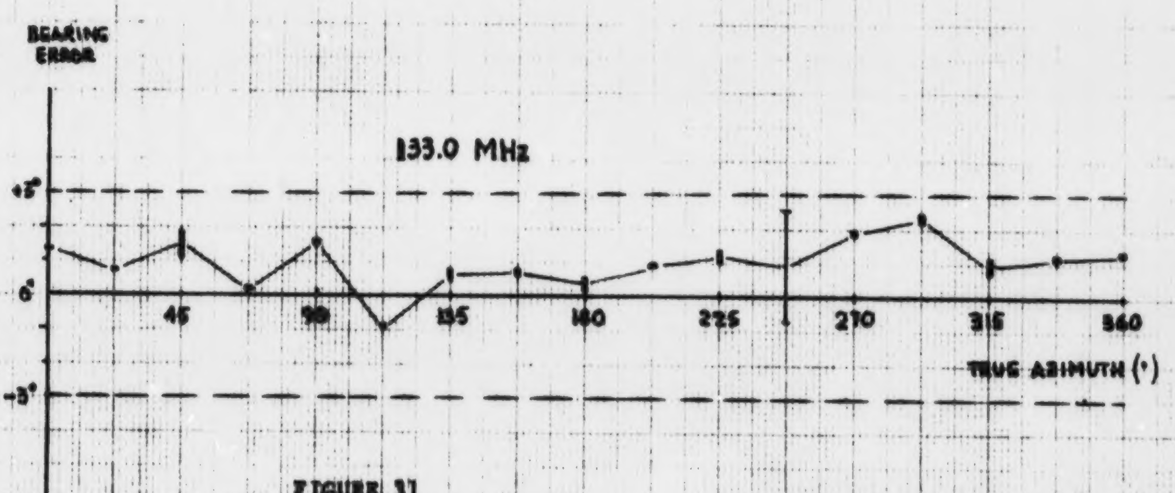

FIGURE 31

D.F. ACCURACY – TARGET ROTATION, F.S. 1 mV/m

DF. ANT. 0° POSITION, SYST. CALIBR. CORR. APPLIED

8.09.83
Z.A.K.

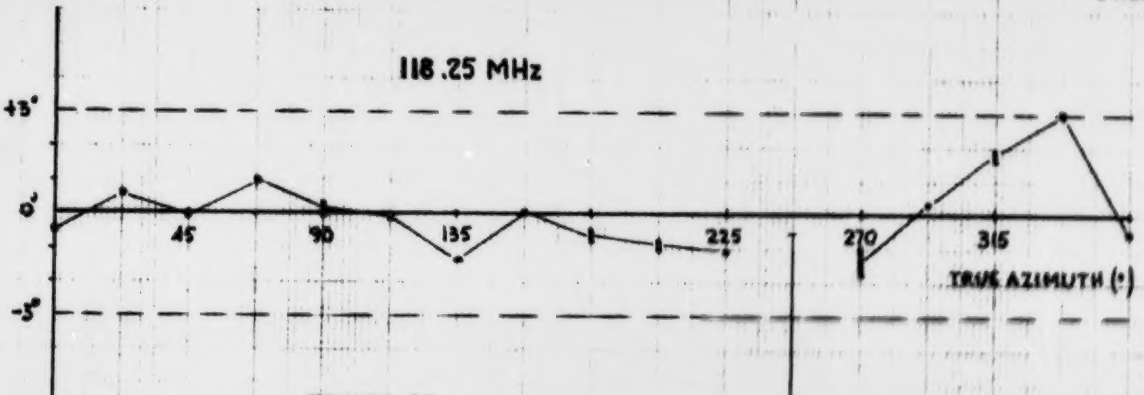

FIGURE 32

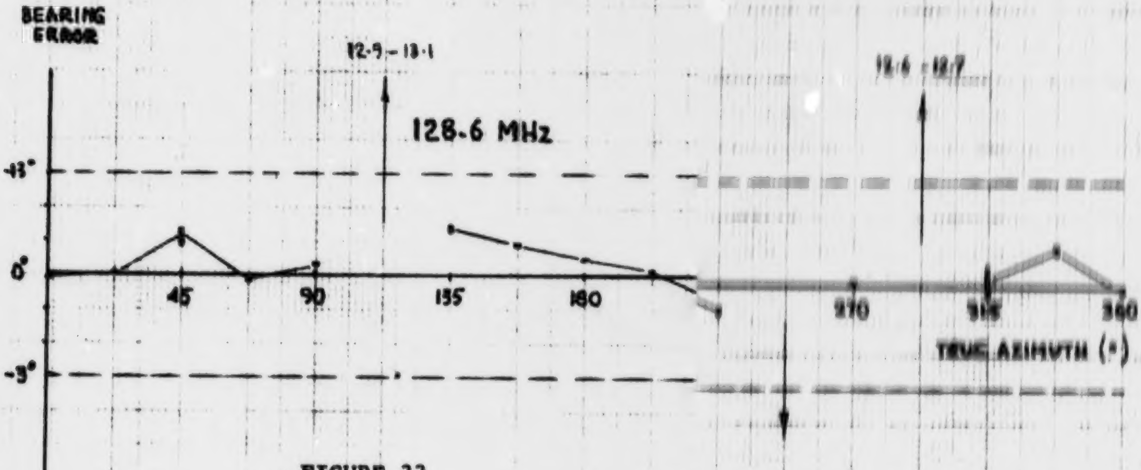

FIGURE 33

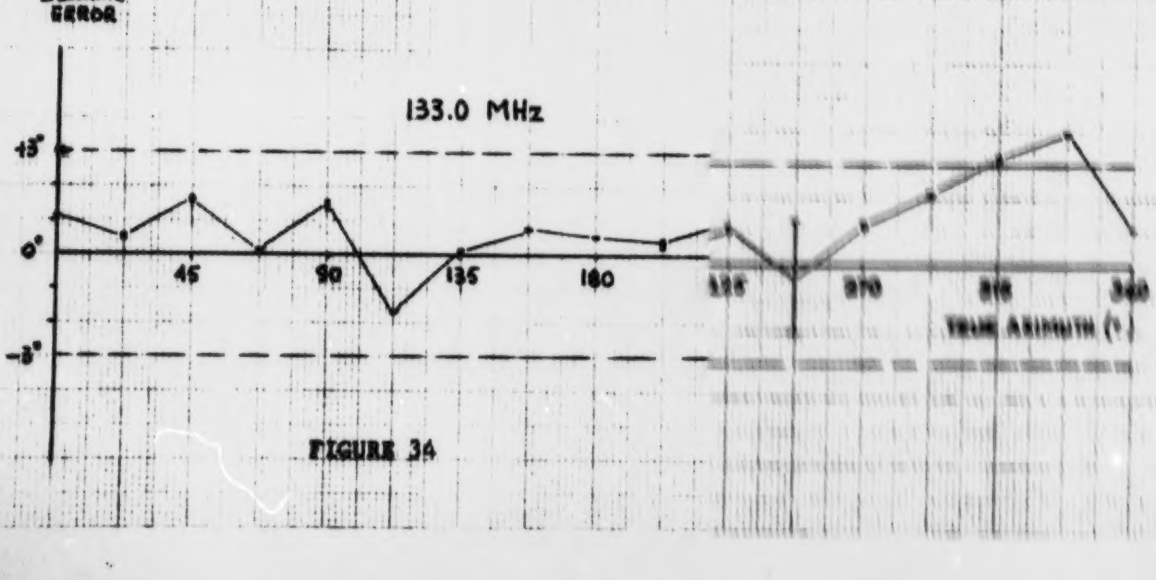

FIGURE 34

COMMENTS

Remarks concerning the 'wild' errors at 247.5° and 292.5° in the Comments to Test No. 3.1 apply equally to all the test results of Test No. 3.2. Other than that, it will be noted that the bearings obtained by target rotation are very similar to those taken when the target was fixed and the antenna was rotated. This indicates that the field site errors are quite small, usually less than 1 degree, i.e. the test site is a very good one for DF purposes.

The test results obtained after the application of calibration corrections show that the bearing errors are within the ±3° limit specified, except for the following:

(a) readings at 247.5° and 292.5° showing excessive errors due to the software problem.

(b) two readings at 133.0 MHz at 337.5° true azimuth where an error of +4° was reached at the minimum and maximum field strength levels.

A common offset of the North bearing by -1.0° should be applied to make the readings mentioned in (b) above fall inside the specification. This offset is available as a preset manual control to be used when installing the equipment.

TEST NO. 4 LOG

Bearing Readout Change WRT Polarization Angle

(Field Strength 50 uV/m) (-14 dBm Signal Gen. Level)

FREQUENCY (MHz)		118.25	128.60	133.00
DF ANTENNA POSITION	Tx ANTENNA POLARIZATION			
0°	Vertical °	000.0	359.3	359.9
	+45°	000.7	359.1	000.9
	-45°	000.3	359.5	359.9
	Change from Vertical (max.)	+0.7	±0.2	+1.0
90°	Vertical °	92.2	90.0	92.3
	+45°	93.9	90.8	90.8
	-45°	92.3	91.2	91.9
	Change from Vertical (max.)	+1.7	+1.2	-1.5
180°	Vertical °	180.1	180.4	179.9
	+45°	180.4	180.6	181.1
	-45°	179.7	180.3	179.8
	Change from Vertical (max.)	-0.4	+0.2	+1.2
270°	Vertical °	268.8	266.1	267.2
	+45°	267.4	268.8	267.4
	-45°	268.2	268.0	268.4
	Change from Vertical (max.)	-1.4	+2.7	+1.2

COMMENTS:

A ±45° tilt of the transmitter antenna may produce a change of bearing reading of up to 2.7° depending on target position and frequency. The standard deviation of all the changes is <1.0°.

TEST NO. 5 LOG

Adjacent Channel Breakthrough Effect on Bearing Readout (CW Mode)

Wanted Signal (Tx No. 1): 50 µV/m, 0° Azimuth

Unwanted Signal (Tx No. 2): 1.5 mV/m, 90° Azimuth

WANTED SIGNAL FREQ. MHz Tx No. 1	UNWANTED SIGNAL FREQ. MHz Tx No. 2	BEARING READOUT (Degrees)		BEARING READING (Degrees)	BEARING CHANGE (Degrees)
		Min.	Max.	Average	Max.
128.600	OFF	0.0	0.1	0.05	0.0(Ref.)
128.600	128.625	357.4	1.6	359.5	-0.55
128.600	128.620	353.8	359.4	356.6	-3.35
128.600	128.615	341.7	352.0	346.85	-13.2

COMMENTS:

The bearing change is well within 3° for an interfering signal transmitting in the adjacent channel (25 kHz away) and set to a level 30 dB higher than the wanted one.

TEST NO. 6 LOG

Effect of Two Test Signals Received in the Same Channel and Angularly Displaced by 90° (CW Mode)

Transmitter No. 1: 0° Azimuth, Frequency 128.600

Transmitter No. 2: 90° Azimuth, Frequency 128.600

Tx NO. 1 LEVEL µV/m	Tx No. 2 LEVEL dB	BEARING READOUT (Degrees)	BEARING CHANGE (Degrees)	REMARKS
50	OFF	0.1(Ref.)	0.0	
50	-10 dB	0.1	0.0	
50	-8 dB	352.8-2.2	-2.6	-50% blank
50	-6 dB	352.6-1.9	-2.85	-60% blank
50	-4 dB	339.9-2.4	-8.95	-75% blank
50	-2 dB	-		-95% blank
50	0 dB	-		-99% blank
50	+2 dB	-		-95% blank
50	+4 dB	307-207.2	-103.0	-90% blank
50	+6 dB	277-289	-77.1	-75% blank
50	+8 dB	267.1-268.4	-92.35	
50	+10 dB	266.5-268.5	-93.6	

COMMENTS:

When two signals are received in the same channel, the stronger one takes over at a field strength difference of 8-10 dB. When the two signals are comparable in field strength level (< 10 dB) the bearing reading is mostly blanked out.

TEST NO. 7 LOG

Bearing Reading Change for High Angle Elevation with Overhead Pass Indication

Test Transmitter: **0° Azimuth, 128.6 MHz**
Signal Generator set to -22 dBm
(F.S. = 50 µV/m at 180 ft. away)

Receiver set to automatic AGC.

TEST Tx DISTANCE	PHASE DET. p-p AMPLITUDE	COMPUTED ELEV. ANGLE		BEARING READING	OHD LIGHT	REMARKS
(d)		Physical*	Electrical**			
180'	3.7cm	0° (Ref.)	0° (Ref.)	0.2°	OFF	Horiz. Ref.
9'8"	2.1cm	62°	55°	Note 1	OFF	
8'6"	1.8cm	65°	61°	Note 1	ON/OFF	Intermittent
5'0"	1.2cm	75°	71°	Note 1	ON	

d = distance between DF antenna and test transmitter

h = height of DF antenna above test transmitter antenna = 18.8 ft.

* = physical elevation angle = $\tan^{-1} h/d$

** = electrical elevation angle = $\cos^{-1}$ (phase det. amplitude reduction ratio from horiz.)

Note 1: At close distances to the DF mast it is not possible to establish accurately the position of the test transmitter antenna.

SPECIFICATION:

Overhead light: greater than 60° ±5°

COMMENTS:

This simulated elevation test is not accurate enough to measure bearing errors due to change in test transmitter elevation. It does, however, verify correct operation of the Overhead Pass Indication, which is within the specified limits.

APPENDIX 6

MODIFICATIONS AND FINAL TEST RESULTS

MODIFICATIONS AND FINAL TEST RESULTS

Introduction

The results of the Field Test Demonstration, carried out in early September 1983, have shown a fault in the software of the bearing processor of the equipment under test, displaying 'wild' errors at certain angles of azimuth. This matter was investigated in the month following the demonstration and the software was revised in such a way as to eliminate any future problems. Applying this new software, a new set of DF accuracy curves was obtained, both for antenna rotation and for moving around with a transmitting target. The enclosed test results show performance of the system without any calibration corrections.

Identification of Fault

Output waveform of the phase detector was examined on the oscilloscope with the DF antenna rotated through the angles of azimuth where the 'wild' bearing errors were recorded. One common factor was observed: the errors occurred when the peaks of the waveform were coinciding with the 'North' pulse position. If the peak exceeded ±180° (the limits of linearity of the phase detector) then the inversion of the phase detector was not taking place. Consequently, the bearing reading was in error due to one of the sixteen samples being out of place. Studying the timing sequence has shown that, in the 'North' position, the microprocessor had no time to reset the phase detector inversion for the normal operation of the following scan. The error has not shown up in the in-plant testing because the antenna simulator used for the purpose does not exactly reproduce the phase sampling waveform as obtained from the DF antenna with an external target transmitter.

New Software Program

The problem is restricted to a relatively short program of the first microprocessor, which prepares the phase pulses of the phase detector output for evaluation by Fourier analysis. The objective is to prevent sample readings in excess of ±180° to produce significant errors in calculation of the bearing angle. The method used was to invert the phase detector whenever such an outsize sample occurred, and to subtract 180° from the result so as to obtain the correct value. The method depended on correct judgement as to which samples required inversion, and on the time necessary to carry out the operation. It also necessitated the linearity of the phase detector to be extremely precise, or else inverted, and non-inverted readings would not be the same.

With the new antenna construction, a better symmetry is achieved of the antenna pattern and the phase detector waveform may only just touch the ±180° limits, even at the extremes of the frequency range. In such cases, peak clipping of the waveform is a much simpler solution than the detector inversion and correction procedure, which was developed for the first prototype.

A new software program was prepared for the first microprocessor, which registers plus or minus 180 degrees for any sample where the phase exceeds those limits. The original 180° noise detector (or 'window comparator') was retained to set the +180° or -180° value when the detector output is swinging between the two limits due to external noise. The new program is much shorter, requiring approximately one third of the number of steps as compared with the original one. The hardware for Fourier analysis and the second microprocessor program of data handling have been left without any changes.

Test Results Using New Software

After installing the new software PROM, the operation of the equipment was verified, first with an antenna simulator, and then with the DF antenna and an external target transmitter. DF accuracy performance was compared with that of the original program and tests were made to detect the effects of noise or any phase mis-match of the receiver channels. As a result, no detrimental effects were observed under any marginal conditions and a number of advantage points were clearly established:

(a) Any 'wild' errors, due to malfunction of detector inversion, were completely eliminated.

(b) The response of the system to a signal coming on is much faster (less than one second) due to a shorter program in computing the bearing.

(c) The bearing readout is more steady, owing to reduction of spreads due to noise or frequency jitter which were present with detector inversion.

Phase matching of the DF receivers and of the antenna switches was checked and touched up where required, both across the RF band and for the full range of signal levels.

The final results of the DF accuracy tests, using the new program, are shown in the attached graphs. Figures 1-3 show the bearing errors for antenna rotation at the test frequencies of 118.25 MHz, 128.6 MHz and 133.0 MHz, and at a field strength level of 50 uV/m. Figures 4-12 show similar curves obtained with the antenna fixed at 0° position, and the target transmitter moved around in steps of 11.25 degrees. Three levels of field strength (5 uV/m, 50 uV/m and 1 mV/m) were used for the target rotation tests. The above results represent the performance of the system without any calibration corrections in the processor software.

Observations and Conclusions

The new software of the first microprocessor entirely eliminates bearing errors due to faulty operation in certain marginal conditions (noise, reflections, distortions of antenna pattern, etc.). The results of DF accuracy measurements in the field show consistent and repeatable readings within the limits of ±2° without the need for calibration corrections. The operatiion is now faster, more accurate, and completely reliable.

DF SYSTEM ACCURACY - ANTENNA ROTATION

TARGET POSITION 0°, FIELD STRENGTH 50 µV/m

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2AK.

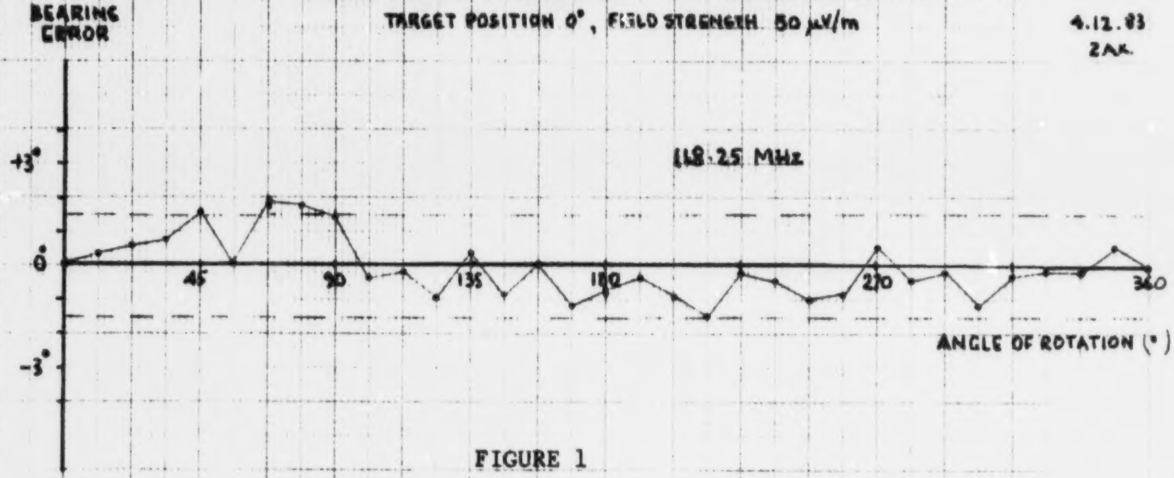


FIGURE 1

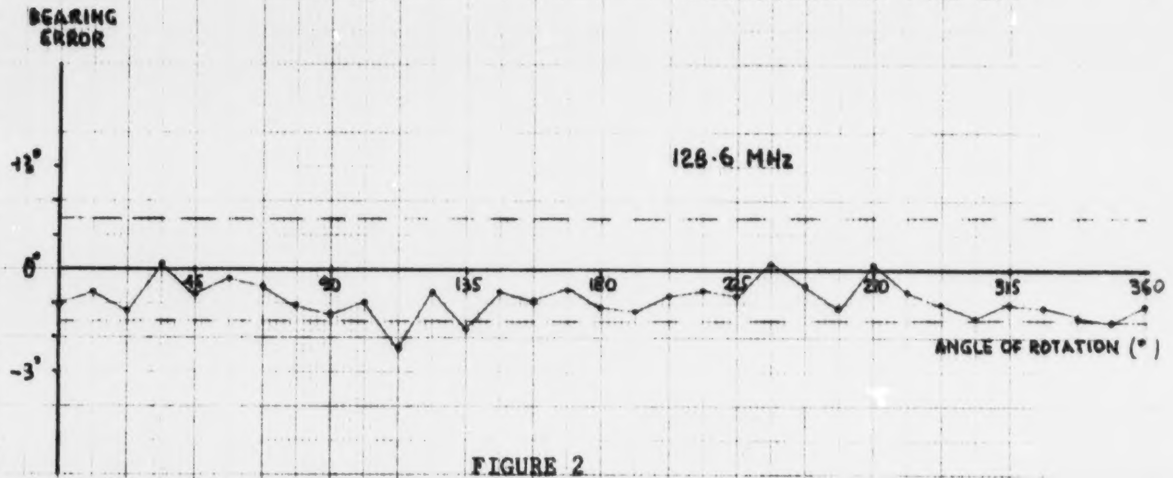


FIGURE 2

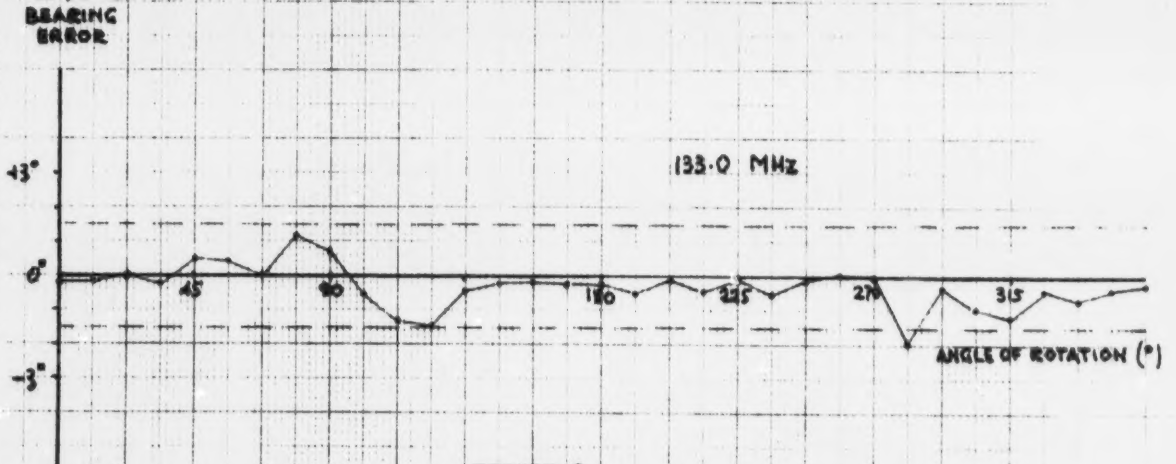


FIGURE 3

DF SYSTEM FIELD ACCURACY

DF ANT. POSITION 0°

FIELD STRENGTH LEVEL 5μV/m

5.12.83
2AK

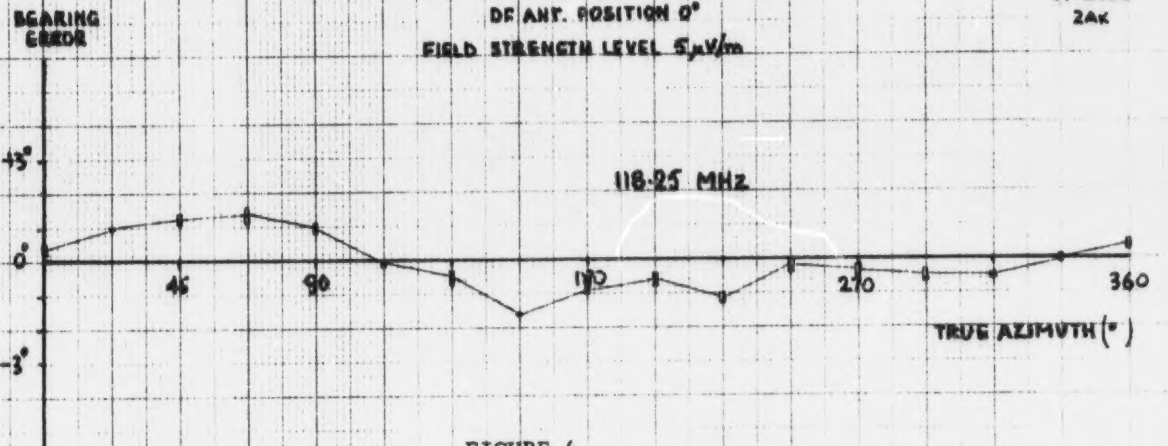


FIGURE 4

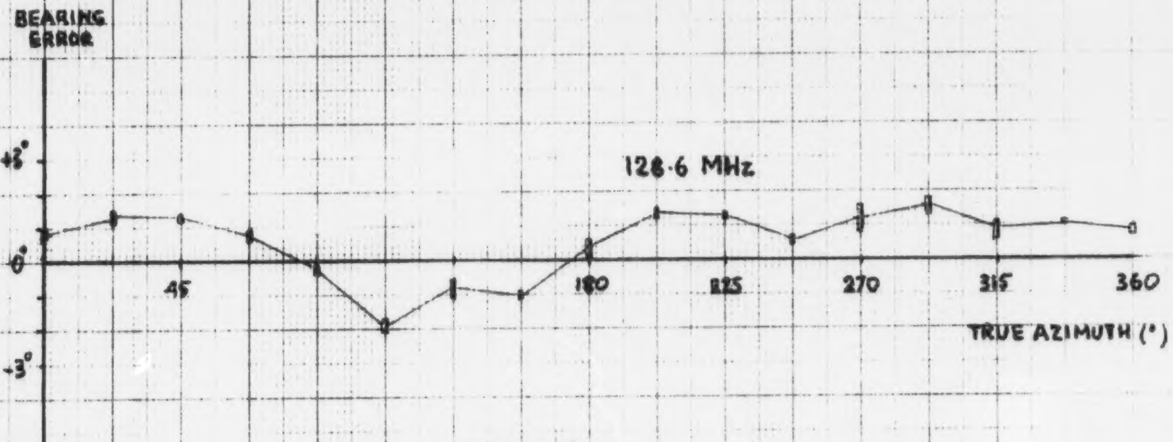


FIGURE 5

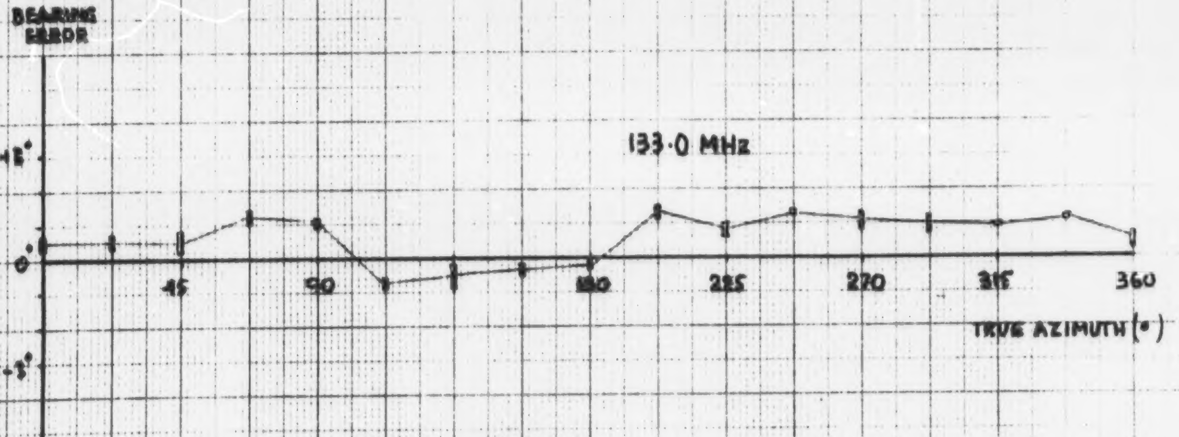
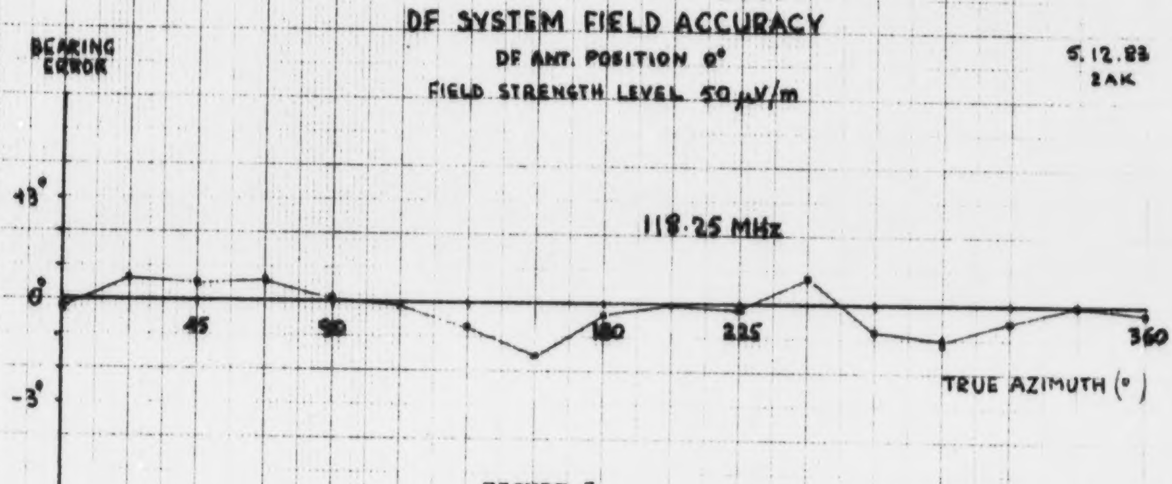


FIGURE 6



DF SYSTEM FIELD ACCURACY

DF ANT. POSITION 0°

FIELD STRENGTH LEVEL 50 μV/m

5.12.83
2AK

FIGURE 7

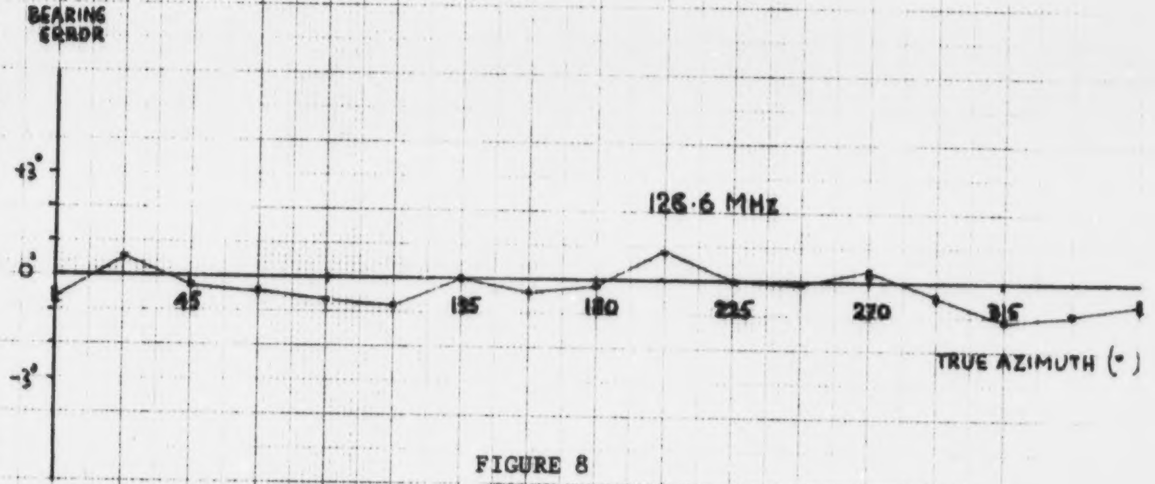


FIGURE 8

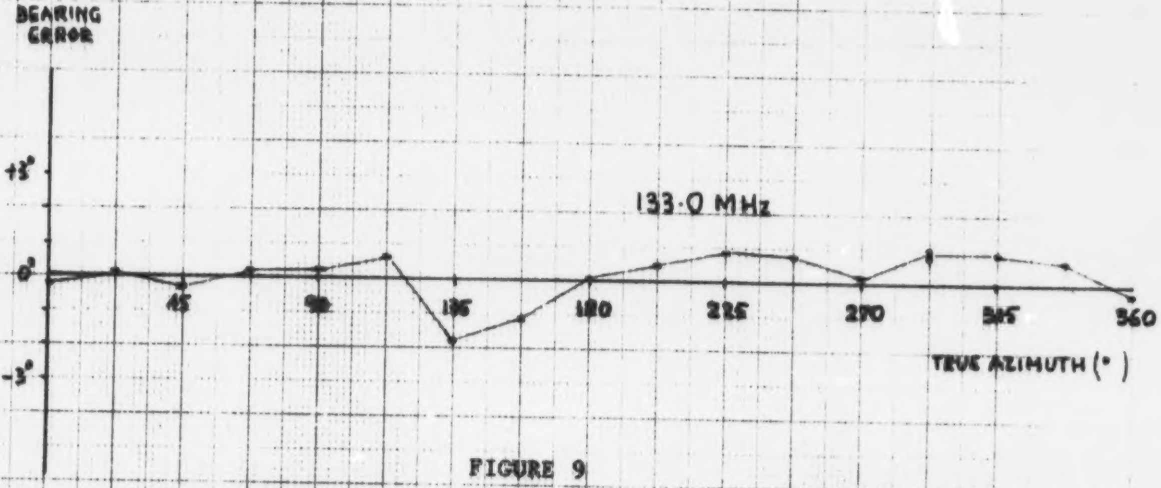


FIGURE 9

40 1513

DF SYSTEM FIELD ACCURACY

DF ANT. POSITION 0°

FIELD STRENGTH LEVEL 1mV/m

5.12.88
ZAK

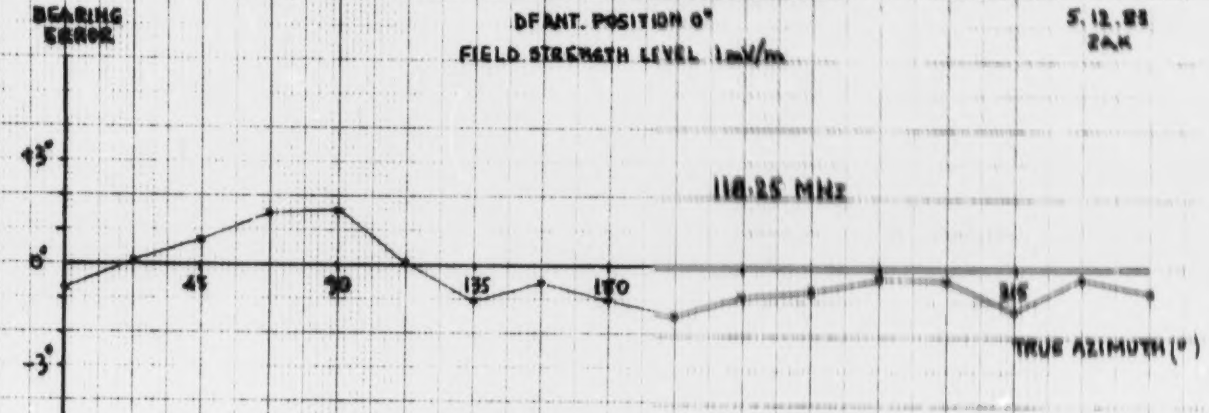


FIGURE 10

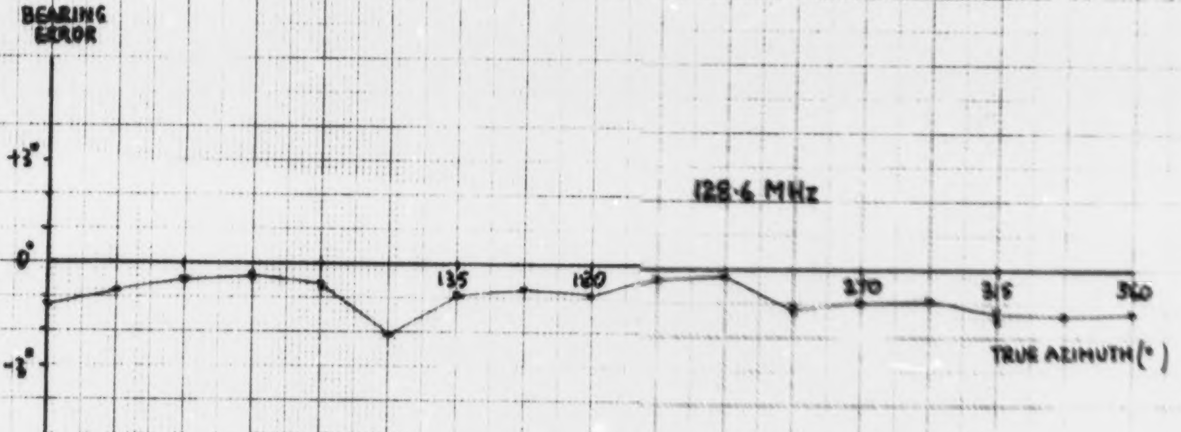


FIGURE 11

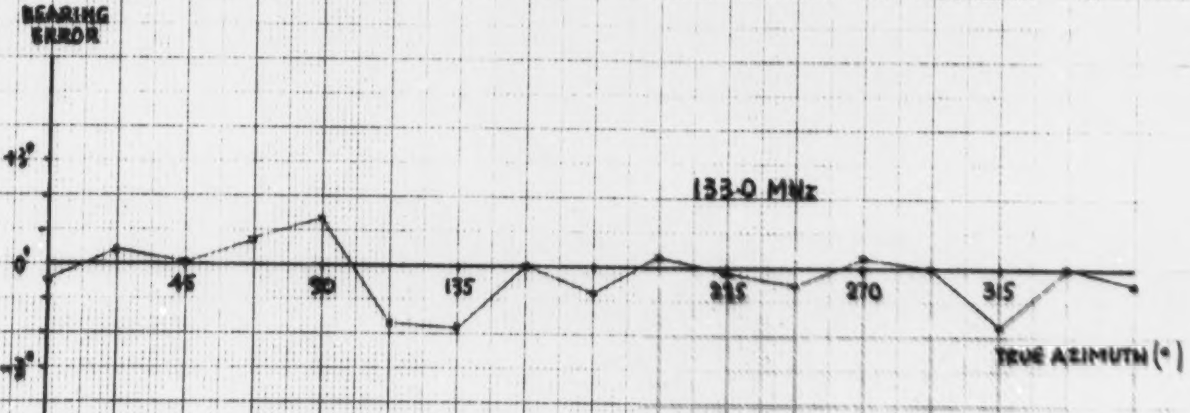


FIGURE 12

APPENDIX 7

DESIGN IMPROVEMENTS

TECHNICAL NOTES

TECHNICAL NOTES

TABLE OF CONTENTS

Title	Author
Interaction of Antenna Elements	Z.A. Krajewski
Antenna for Ground Base Doppler DF	Z.A. Krajewski
Final Test on Antenna Commutator Performance	D. Pierce
Built-in Test Facilities	Z.A. Krajewski

BAYLY
ENGINEERING
LIMITED

DOPPLER CIRCULAR ARRAY

INTERACTION OF ANTENNA ELEMENTS

1. Optimum termination of unused dipoles.

The choice has been questioned of the use of nominal impedance for the termination of the unused dipoles in the Doppler DF circular array. The reference which gave rise to the argument was that from Earp and Godfrey article of 1946 (ref. 1) which quotes:

> **(5.2) Aerial Interaction**
>
> By the partial re-radiation of the received energy, each aerial of the system will set up a signal-frequency field of limited strength covering a limited area. Because of the addition of this interacting field to that due to the direct signal, the resultant voltages induced in any aerials of the system lying within the secondary field of another will have phases which will be slightly different from the correct values. Obviously, if the effect is severe the disturbance of phase is sufficient to invalidate the bearing indicated.
>
> Experiment has shown that, if aerial interaction is not to be severe, any aerial, including its earth image, must be less than $\frac{1}{4}\lambda$ long, or, if longer, must be broken into sections less than $\frac{1}{4}\lambda$ in length by the inclusion of series resistors at suitable points. The permissible length varies with the adjacent aerial separation and with the manner in which the aerial is terminated. For instance, an earthed $\frac{1}{4}\lambda$ section will produce a very strong interaction over long distances, whereas with 500 or 1 000 ohms inserted in the earthed end the effect is reduced by at least four times, and is noticeable only over distances within a wavelength of the interacting element. If $\frac{1}{4}\lambda$ aerials are used, as is advisable for good sensitivity, and their separation is not large compared with the wavelength, it is imperative to arrange that at the instants in the commutation cycle when an aerial is not being used for reception it shall have as little interactive effect as possible. In general, a high impedance is switched into the base of such an aerial at all times except when it is required to receive the signal.
>
> It is possible to show that interactions that affect the phasing of the various aerials in only a small degree may cause quite intolerable bearing errors.

The author's statement is rather general, quoting the well-known phenomenon of re-radiation from a $\frac{1}{4}$-wave monopole. No practical figures are given for the improvement with high-resistance loading.

Nine years have passed until the subject was approached in a more scientific manner by Bain (ref. 2 article published in 1955). Bain experiments with rotating a reflecting element around a test antenna and introduces a concept of "interaction ratio" which is the ratio of the radius of the locus circle in the phase-amplitude plane to its centre distance from the origin. In more practical terms the "interaction ratio shows the extent of variation of the reflected wave with azimuth and frequency. Bain shows that this variation is least when the re-radiating element is terminated in it'snominal impedance.

An interaction ratio curve for a particular experiment and a set of conclusions are shown below:

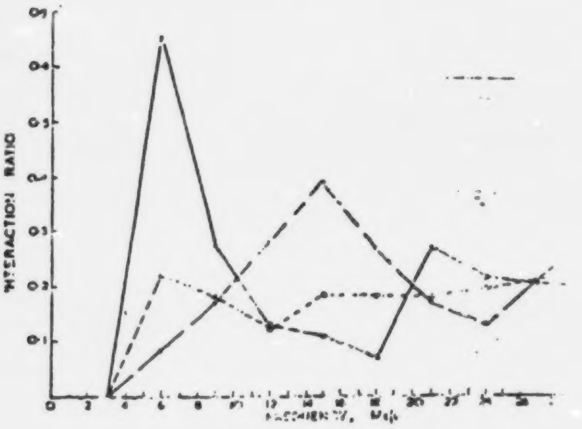


Fig. 4.—The interaction ratio from the aerial interaction loci.

Termination of portable aerial:
× Short circuit.
● Open circuit.
○ 100-ohm resistor.

(5) CONCLUSIONS

The performance of the cyclical system considered here has been found to be identical for practical purposes whether 36 or 20 fixed aerials are used or a single continuously-rotating aerial under the same specified conditions of wave interference. Such a system gives a substantially lower error variance than the Adcock system if it has an aperture of 4λ, and is better still for an aperture of 10λ.

The aerial interaction experiments revealed that it was best to terminate the aerials not in use by a resistance equal to the nominal aerial impedance (100 ohms). In this case the presence of a single neighbouring aerial of the 24-aerial 100 m-diameter system could alter the phase at an aerial by 9° at the most. An examination of the combined effect of all the aerials in the ring indicated that the error in indicated bearing was likely to be negligible.

Following Bain's work, Earp changes his mind and points out the advantages of nominal-impedance termination in a paper puslished by Earp and Cooper-Jones in 1958 (ref. 3). The authors emphasize the improvement such terminations give for larger antenna arrays and over a wide frequency band.

(4) THE PROBLEM OF AERIAL INTERACTION

One of the outstanding problems in the development of c.a.d.f. systems has been the design of efficient individual aerials which, when not in use, could be disconnected in such manner that they become ineffective as signal reflectors. Aerials not in use behave very much as unwanted site obstacles, producing a distortion of the signal field, and hence equipment errors somewhat similar to site errors. In the circular array, however, some interaction is permissible, for errors due to different aerials tend to cancel out except for the regular cyclic error which is repeated a number of times per azimuth equal to the number of aerials. As already described by Bain,[2] when the number of aerials is large, one practical solution is provided by terminating the aerials not in use with a suitable dummy load.

To illustrate the principle, suppose that unipoles are used and that the operating frequency range comprises both the $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ modes of operation of the aerials. Open-circuiting such an aerial at the base would leave the aerial resonating freely and providing a maximum interaction with the signal field at the $\frac{1}{2}\lambda$ mode. Short-circuiting of the base to earth would produce a maximum aerial parasitic current in the $\frac{1}{4}\lambda$ mode. Now, such an aerial might have an impedance of 30 ohms at the $\frac{1}{4}\lambda$ mode and 200 ohms at the $\frac{1}{2}\lambda$ mode, so termination by 70–100 ohms not only reduces current several times at the $\frac{1}{4}\lambda$ mode, as compared with the short-circuit condition, but also considerably damps the voltage antinode in the open-circuit $\frac{1}{2}\lambda$ case. Because of its simplicity this technique has been adopted whenever possible for equipment of wide frequency coverage, but since parasitic aerial currents are not reduced by a very large factor, it does not represent an adequate protection against serious variations of signal pick-up at different aerials, and serious repetitive errors, too, unless the number of aerials is 18 or more.

Despite the essential compromise involved, the termination technique has certain advantages. For example, if the aerial termination is not modified by aerial commutation, no keying modulation can be imposed on other aerials in the vicinity. This has particular significance when, say, an aerial at the centre of the circular array is used as a frequency-reference or listening-through aerial. Another point which has proved to be very convenient for ease of development is that aerial interaction can be assessed with great precision simply by measuring signal attenuation between a generator connected to one aerial and a receiver connected to another.

2. Optimum spacing of dipoles.

Derivation of the bearing angle from the fundamental frequency of the phase output dictates that the dipole spacing should not exceed half-wavelength or 180°, otherwise there would be an ambiguity of reading. In practice, this spacing has to be reduced so as not to overload the linear phase detector. This is clearly explained by Earp and Cooper-Jones in the paper of 1958 (ref. 3).

The phase modulation imposed on a signal by smooth gyration of an aerial is sinusoidal, the deviation being $\pi d/\lambda$, where d is the diameter of gyration; and being sinusoidal, can, of course, be translated to an equivalent frequency modulation. The c.a.d.f. signal also bears phase modulation of deviation $\pi d/\lambda$, but the waveform of the modulation contains transients which cannot reasonably be considered as frequency modulation.

In practice, the c.a.d.f. receiver first attempts to measure the differential phase envelope of the signal, the time-constant of differentiation usually being equal to the time of connection to a single aerial, i.e. the time interval of a single horizontal step of the phase envelope. (If this differential phase envelope can be measured, the original phase envelope can be constructed, by integration; but integration is unnecessary for bearing computation, since the differential envelope has a fixed and known phase relation with respect to the envelope itself.)

Now, when adjacent aerial spacing exceeds $\frac{1}{2}\lambda$, differential phase steps may lie outside the range ±180°, so that the differential phase envelope cannot be directly measured without ambiguity. Leaving this case for the moment, let us assume that phase steps do not exceed 180°. In this particular case, which represents the most simple operating regime of a c.a.d.f. receiver, bearing is, in fact, measured by establishment of the differential phase envelope and comparison of this in cyclic repetition phase with the phase of the cyclic aerial commutator.

For those who like to have a more 'physical' explanation of the computation, in this particular case it is possible to provide a satisfactory one. The receiver stores phase information with regard to one signal sample, using a delay network, and subtracts this phase from that of the next sample to provide an unambiguous representation of the phase difference between two adjacent aerials. Hence, the complete process is exactly equivalent to that which would be obtained by commutating a pair of phase-matched receivers to adjacent pairs of aerials, measuring the phase difference at the outputs to yield a succession of values constituting a stepped sine wave, from which the bearing can be measured.

Practical experience has shown that, when the bearing is derived by measurement of the first differential of the phase envelope, it is undesirable to have adjacent aerial spacing greater than $\frac{1}{3}\lambda$. A maximum phase step of 120° gives an adequate margin of safety against breakdown of a linear discriminator, which can deal with phase steps approaching ±180°. The margin of 60° is required for phase errors due to maladjustment of equipment, noise (particularly at full range), site imperfections, and multi-path propagational effects. Now the diameter of a

c.a.d.f. array is substantially determined by the performance required for the lowest frequency of operation, while the number of aerials required is inversely proportional to the maximum phase step which can be handled by the bearing computer. For frequency-band ratios much exceeding 2, a very large number of aerials would be required if the maximum phase step were limited to 120°. In the following Section it is shown that this limit can be raised to 360° without unreasonable complication, so allowing a threefold reduction in the number of aerials, with a substantial saving in cost.

Larger than one third wavelength spacing becomes possible when analysing harmonics of the phase waveform as well as the fundamental. The author suggests that this may become cost effective for wide-band applications.

Similar thoughts are expressed by I.S. Kukes et Al in the well-known textbook on Radio DF (ref. 4):

> **For ensuring a single value the maximum phase difference must be less than π and consequently $d < \lambda/2$. In practice the distance between the antennas is taken in the order of $\lambda/3$. It is possible to increase the distance between the antennas to $d = \lambda$. This corresponds to a reduction in the band of reproduced frequencies by two times which has little effect on the distortion of the shape of the phase modulation curve. For eliminating the multiplicity of indications in this case a two-valued difference comparison of the phase takes place: the voltage with a phase difference (8.75) is delayed in a second filter with a time delay τ and is compared with a voltage which is not delayed [8.19].**

REFERENCES:

1. Radio Direction Finding by Cyclical Differential Measurement of Phase,
   - C.W. Earp and R. M. Godfrey, Journal IEE Vol. 94, Part IIIA, PP 705-721, March 1947.

2. Possible Errors of a Particular Wide-Aperture Direction Finder
   - W.C. Bain, Proc. IEE Part C, Vol. 103 pp 313-324, Sept. 1956.

3. The Practical Evolution of the Commutated-Aerial Direction Finding System
   - Proc. IEE, Vol. 105, Part B, supplement no. 9, pp 317-325, March 1958. C.W. Earp and Cooper - Jones

4. Principles of Radio Direction Finding
   - I.S. Kukes et Al, Moscow, 1962 (translated by the National Technical Information Service, USA).

20.05.82

Z A Krajewski

02.06.82

ANTENNA FOR GROUND BASE DOPPLER D.F.

- ALTERNATIVE CONFIGURATION

by: Z.A. Krajewski

1. BACKGROUND

The original Quasi-Doppler DF Antenna developed for ATC by Bayly Engineering consisted of 16 dipole elements supported in a horizontal circle by a rigid rim of insulating tubing and utilizing a metal wire spoke pattern for its ground plane of symmetry. The dipole outputs converged symmetrically to the centre of the array, where they were fed into the antenna unit enclosure which was a waterproof box containing the scan commutator and the two front end circuits of the receivers. This box was located on the centre mast, directly below the lower tension cone of the antenna structure.

In this elevated position, the box contributed to a number of advantages which the system could offer as compared with other configuration approaches.

(1) Dipole cables, which have to be carefully phase matched, are very short.

(2) Insertion loss ahead of the RF front end is greatly reduced.

(3) Signals containing bearing information are sent down at the 1st intermediate frequency and at a higher level, thus reducing chances of interference pick-up along the mast.

(4) Losses and matching of the down-the-mast cable become relatively non-critical and costing is minimized.

(5) There is no need to feed up the mast a bundle of control cables carrying high level switching pulses needed to activate the commutator diodes.

(6) The entire front-end grounding is confined close to the ground symmetry plane of the array.

The mast mounted antenna unit has been designed with utmost care to provide reliable operation over the extensive temperature range (outside exposure) of -55°C to +45°C. The internal design allowed for easy replacement of modules, the fault finding of which can be performed from the cabin below. Nevertheless, criticisms have been raised about the difficulty of access to the unit, especially during severe arctic weather conditions.

The original design was made up on a careful balance of conflicting requirements of sensitivity, accuracy, interference functioning, etc. By placing more weight on maintenance, it is possible to present an alternative configuration, locating the antenna unit box in the cabinet below the mast, at the expense of certain other parameters. It is the purpose of this report to outline the advantages and disadvantages of this configuration.

2. CABIN MOUNTED ANTENNA UNIT

For easy maintenance, the best approach is to install all of the antenna unit electronics inside the cabin located at the foot of the mast. In this way, all the routine checks and repairs can be done from the inside of the cabin, and the only outdoor replacements may be those of the dipoles damaged by lightning. This design stipulates that the phase matched cables from the dipoles to the commutator have now to be lengthened by the full height of the mast.

Advantages

- easy access in temperature controlled conditions for alignment and repair
- reduced range of environmental spec.
- improved profile of the mast structure (reduction of site errors)
- reduced length of the 4 existing down-the-mast cables

Disadvantages

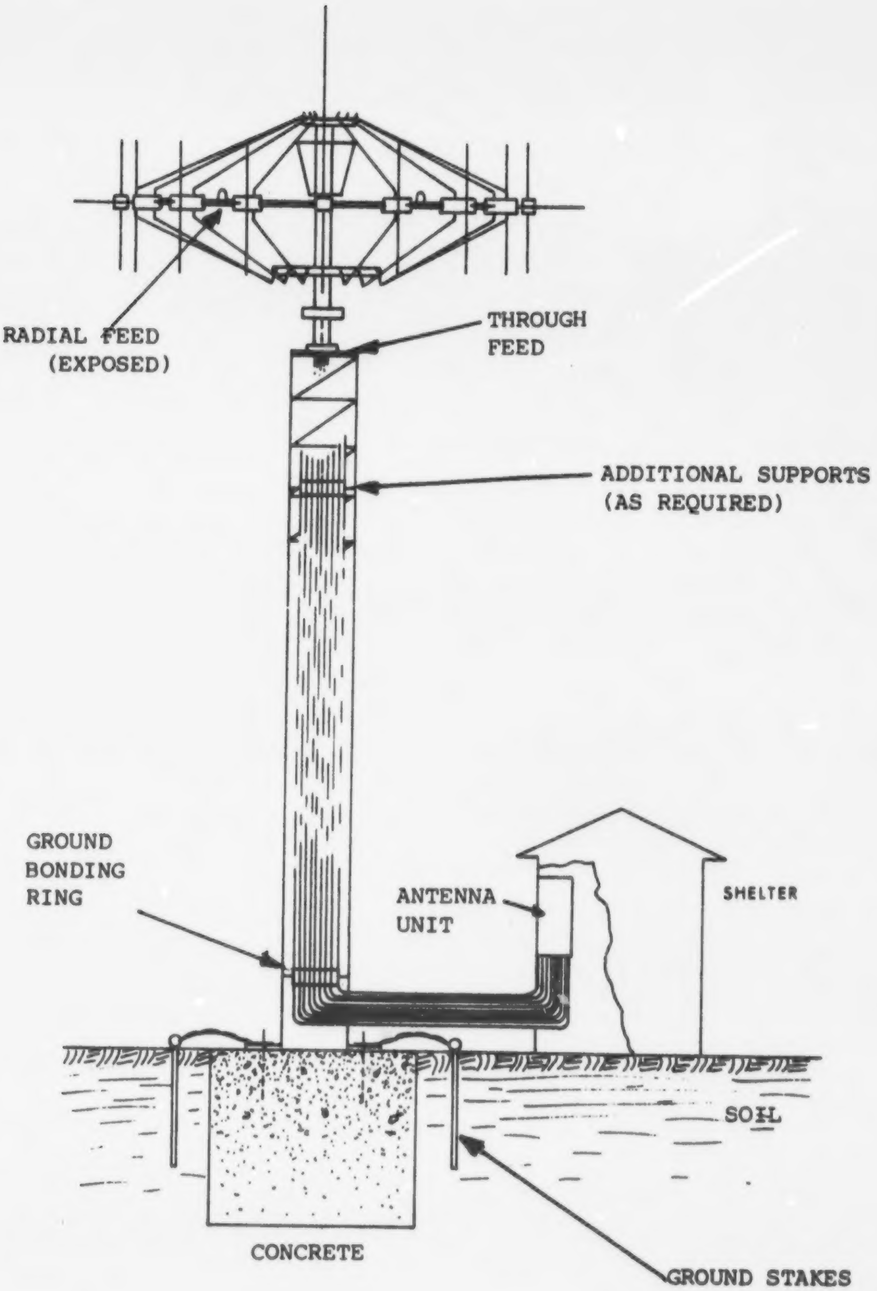
- greatly increased total length of dipole to commutator cables, reduction of sensitivity
- increased vulnerability of above cables to meet interference
- increased cost of cables and connectors suitable to meet acceptable r.f. loss and provide additional shielding
- requirement of accurate ground bonding at the base of the mast

Summarizing from the list of disadvantages, it will be seen that the new configuration can be made to work, provided:

(1) The dipole to commutator cables are of very low loss and are provided with excellent RFI shielding.

(2) The phase matching of the above cables can be handled adequately over the entire RF band.

(3) Secure and accurate ground bonding is provided to prevent the shield currents entering the cabin.


RADIAL FEED (EXPOSED)
THROUGH FEED
ADDITIONAL SUPPORTS (AS REQUIRED)
GROUND BONDING RING
ANTENNA UNIT
SHELTER
SOIL
CONCRETE
GROUND STAKES

QUASI-DOPPLER ANTENNA INSTALLATION IN ALTERNATIVE CONFIGURATION

Because of the additional RF losses (and cost of cable assemblies) it will not be possible to offer the original antenna head to receiver distance of 50 m in this configuration. A 50-60 ft. maximum appears to be a practical limit for a less expensive cable (1/4" dia). Thicker cables, 3/8", or even 1/2" dia., could secure greater extension at a higher cost.

The distance limitations of the alternative configuration make it desirable to maintain the antenna unit in an unchanged design so that it can be used for both applications - inside the cabin with shorter antenna masts in bad weather areas, or on top of the mast on high locations, in a milder climate; especially where the interference problems are more severe (control towers, radar masts and others).

3. THE ALTERNATIVE CABLE AND MAST CONFIGURATION

The dipole cable follows the radial path, as in the present design, but then it enters a hole in the mast and is fed down inside the mast tube, through the mounting flange and down the centre of the lattice mast.

A ground bonding ring is provided to secure a symmetrical ground connector to the shield of each cable at an exact distance X from the respective dipole.

The cables enter the cabin at floor level after leaving the bonding ring. From there, they are fed into the antenna unit box (or boxes).

It is desirable to add phase matching facilities at the input to each antenna switch (approx. ±2.5°), particularly for the marine version where better matching of all the dipoles is required.

4. COST AND PERFORMANCE COMPARISON

Based on long term experience with DF equipment installed on Canadian Navy Ships, a suggestion was made to use Andrew Antenna Cable 1/4" Foam Dielectic Heliax" type FHJ-50 or its phase stabilized version, type 35422-11 (this is a low loss cable with a solid copper shield most effective in suppressing outside interference). Loss at 150 MHz is approximately 2 dB/100 ft.

22.06.82

DEVELOPMENT OF DOPPLER D.F. SYSTEM FOR ATC

FINAL TEST ON ANTENNA COMMUTATOR PERFORMANCE

by: D. Pierce

This report describes the final testing of the antenna commutator switch.

The schematic diagram for the coax switch is shown in Fig. 1. Three modifications have been made to improve the switch performance. R13 was added to ensure D5 is fully reversed biased when the dummy load is not selected. C16 was added to ensure the two RF output channel lines can be phase matched with respect to the dipole input. The third modification involved changing the dummy loads from 50 Ohms to 75 Ohms to reduce the reflections from non-selected dipoles. The 75 Ohm output impedance of the dipole is now correctly matched to the dummy load.

The soft switching waveform, along with the sampled RF pulse, is shown in Fig. 2. This waveform is generated by integrating the scan clock square wave pulses to form a triangle wave, then amplifying this signal to clip the peaks off flat. As formerly concluded, the shape of the centre portion of the soft switching waveform is far less important than the shape of the switching waveform during the first few degrees of conduction. The first few degrees of RF conduction occur near the zero crossing of the soft switching waveform. The slope of this waveform is reduced at the zero crossing by driving the waveform through a passive network of resistors and dipoles. The slope of the diode's conduction knee is used to provide soft switching for both the turn-on and turn-off of the RF signal, with the minimum slope occurring at the zero crossings.

The 'turn-on' of the RF pulse is clearly shown in Fig. 3. The effect on the soft switching can be seen by examining the slow rise time of the RF pulse.

The test set up for the measurement of the intermodulation products is shown in Fig. 4. The results of the tests are shown in Fig. 5, 6, and 7. Figures 5 and 6 show the difference in level of intermodulation distortion between soft switching and square wave switching. Figure 7 shows that the intermodulation products are 35 dB down at ±25 kHz or one channel spacing away from the centre frequency.

CONCLUSION

These results show the importance of using a soft switching approach. Although the actual sampling of the RF pulse by the timing circuitry occurs in the middle of the pulse, the elimination of higher order intermodulation products can reduce the unwanted phase noise in the receiver.

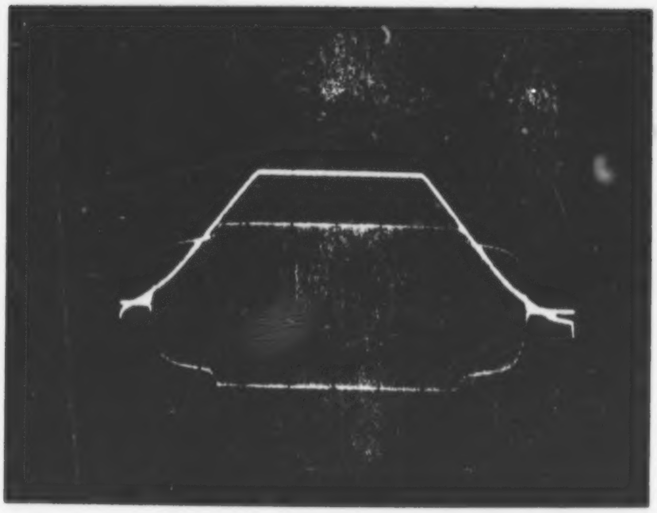


FIG. 2: SOFT SWITCHING WAVEFORM WITH RF PULSE
VERTICAL: 5 Volts/DIV
HORIZONTAL: .1 msec/DIV

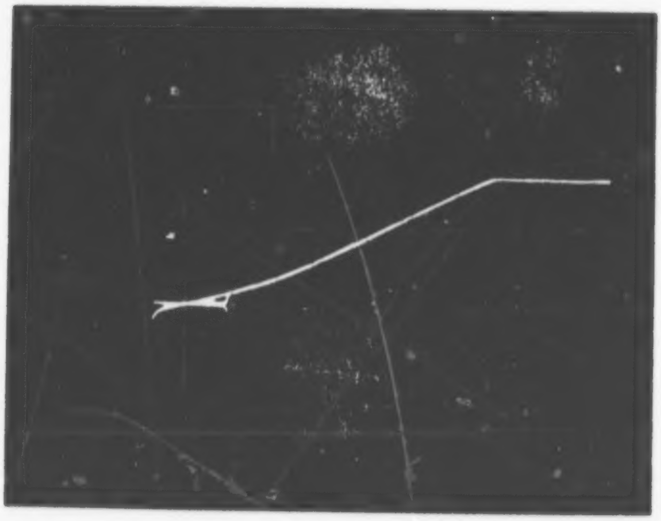


FIG. 3: SOFT SWITCHING WAVEFORM TURN-ON WITH RF PULSE
VERTICAL: 5 Volts/DIV
HORIZONTAL: .05 msec/DIV

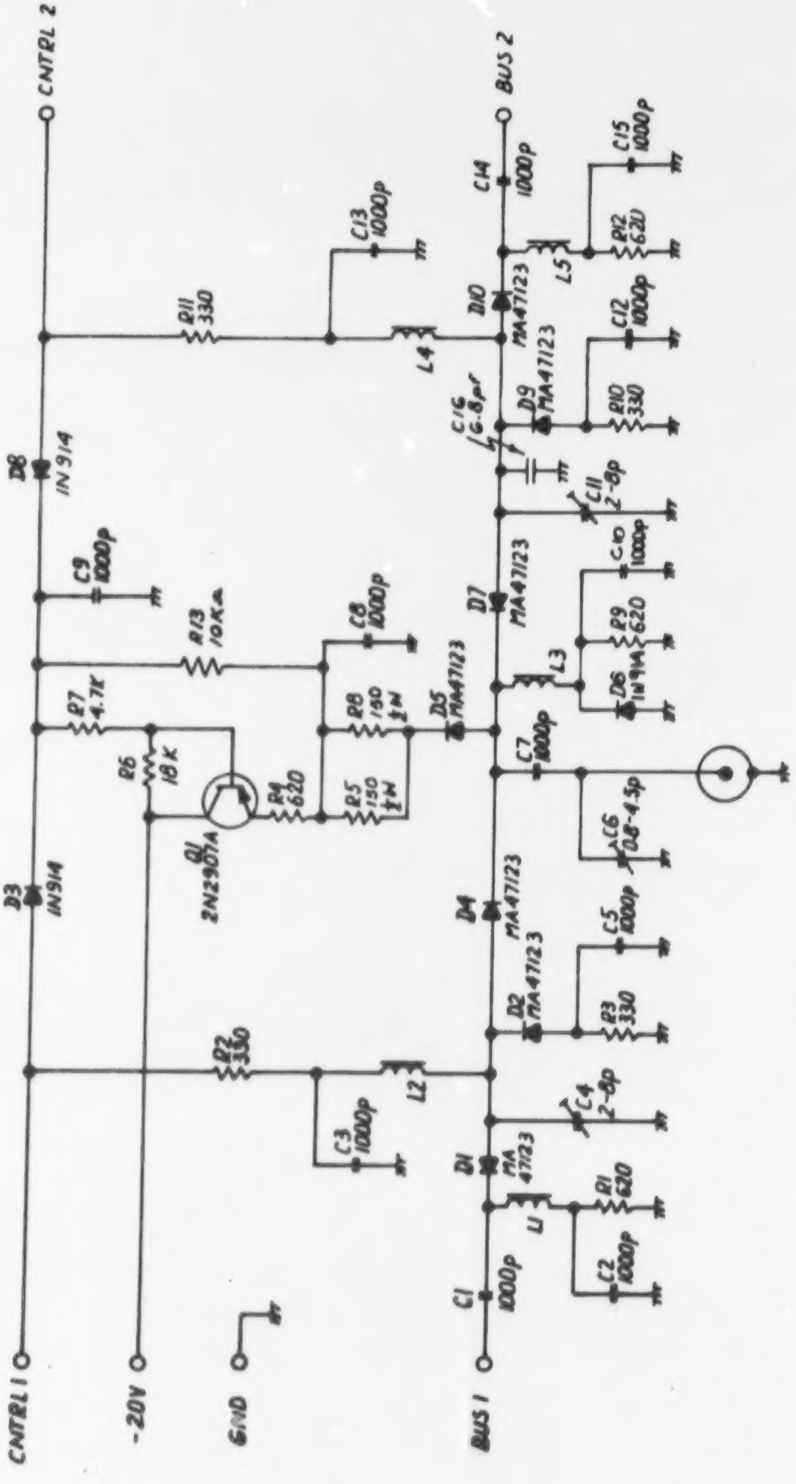

CNTRL 1
CNTRL 2
-20V
GND
BUS 1
BUS 2
D3 IN914
D8 IN914
C9 1000p
R13 10KΩ
R7 4.7K
R6 18K
Q1 2N2907A
R4 620
R5 150 ½W
R8 150 ½W
C8 1000p
R2 330
R11 330
C3 1000p
C13 1000p
L2
L4
C1 1000p
L1
D1 MA 47123
R1 620
C2 1000p
C4 2-8p
D2 MA47123
R3 330
C5 1000p
D4 MA47123
C6 0.8-4.5p
C7 1000p
D5 MA47123
L3
D6 IN914
R9 620
C10 1000p
D7 MA47123
C11 2-8p
C16 0.8pf
D9 MA47123
R10 330
C12 1000p
D10 MA47123
L5
R12 620
C14 1000p
C15 1000p

FIG 1
FINAL COAX SWITCH

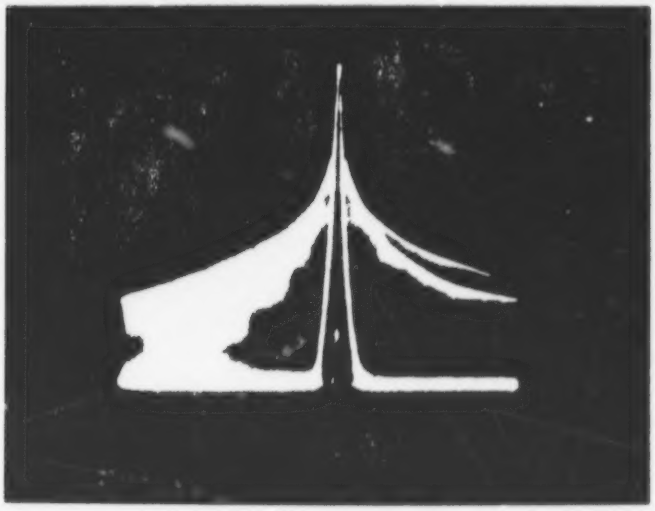


FIG. 5: OUTPUT SWITCHING SPECTRUM WITH HARD SWITCHING WAVEFORM

VERTICAL: 10 dB/DIV
HORIZONTAL: 200 kHz/DIV
CENTRE FREQ.: 126 MHz

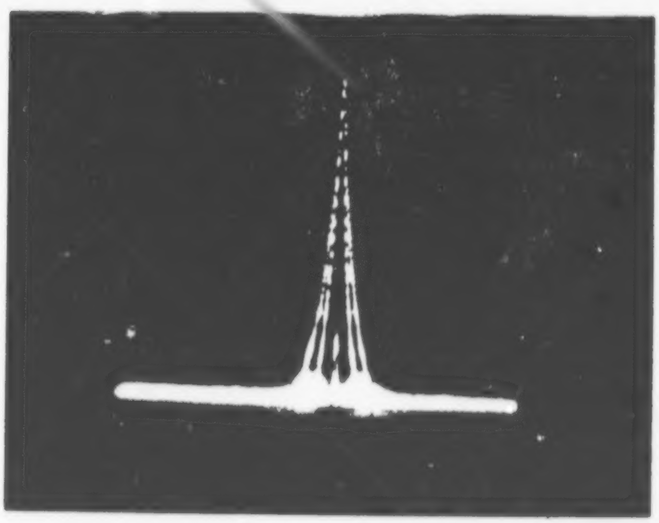


FIG. 6: OUTPUT SWITCHING SPECTRUM WITH SOFT SWITCHING WAVEFORM

VERTICAL: 10 dB/DIV
HORIZONTAL: 200 kHz/DIV
CENTRE FREQ.: 126 MHz

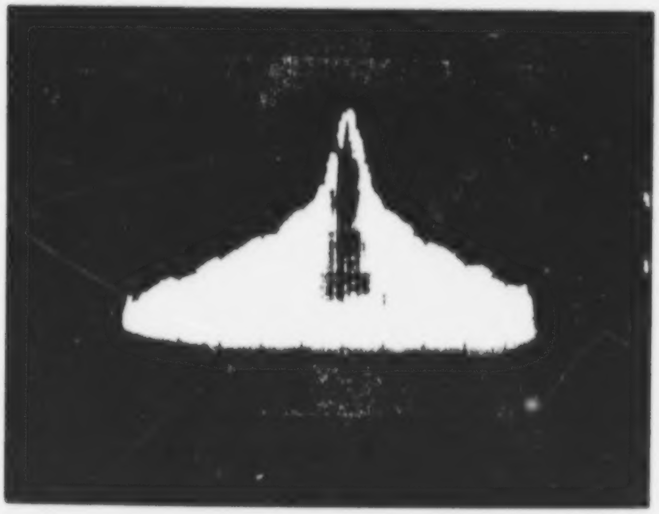


FIG. 7: OUTPUT SWITCHING SPECTRUM WITH SOFT SWITCHING WAVEFORM

VERTICAL: 10 dB/DIV

HORIZONTAL: 10 kHz/DIV

CENTRE FREQ.: 126 MHz

June 16, 1983

BUILT-IN TEST FACILITIES

System Test

A new concept is introduced for extended built-in testing facilities. It is based on a software program of analyzing the operation of the DF system when injected with an RF test signal from the Omnidirectional antenna in the centre of the array. It does away with the original array of four Test Injection Monopoles which have not been proved satisfactory and which are a source of distortions of the DF antenna pattern.

Test Features

1. System Test 45°
2. System Test 315° : Two momentary push-buttons are provided to give an overall check of accuracy of the entire DF system. Performed for two sample azimuth bearings, this test verifies the operation of antenna dipoles and switches, of the DF receiver and phase detector, the digital bearing processor and the associated bearing displays.
3. Signal Overhead Test : Push-button facility provides a check of the signal overhead indicator and alarm.
4. Phase Balance Test : A separate push-button to inject the RF test signal in equal phase to all the dipole pairs provides a facility to examine dipole phase balance and the phase balance of the DF receiver channels with the aid of an external oscilloscope.

Test push-buttons 1, 2 and 3 are for use by the operator and are available on the front panels of both the Receiver and Operator's Control/Displays. The phase balance test push-button is intended purely for maintenance and is located on the Receiver Control/Display only.

Principle of Operation

An RF test signal is generated by mixing the 1st oscillator frequency with the 1st intermediate frequency (30 MHz) derived from a separate crystal oscillator. The test signal is applied via a PIN diode switch to the Omnidirectional antenna in the centre of the array (normally used for the monitoring audio and emergency channels). The scanning action of the Doppler DF system causes the phase detector to deliver a series of step pulses of near-zero amplitude, which can be used for a phase-balance check of the system and for trouble-shooting purposes.

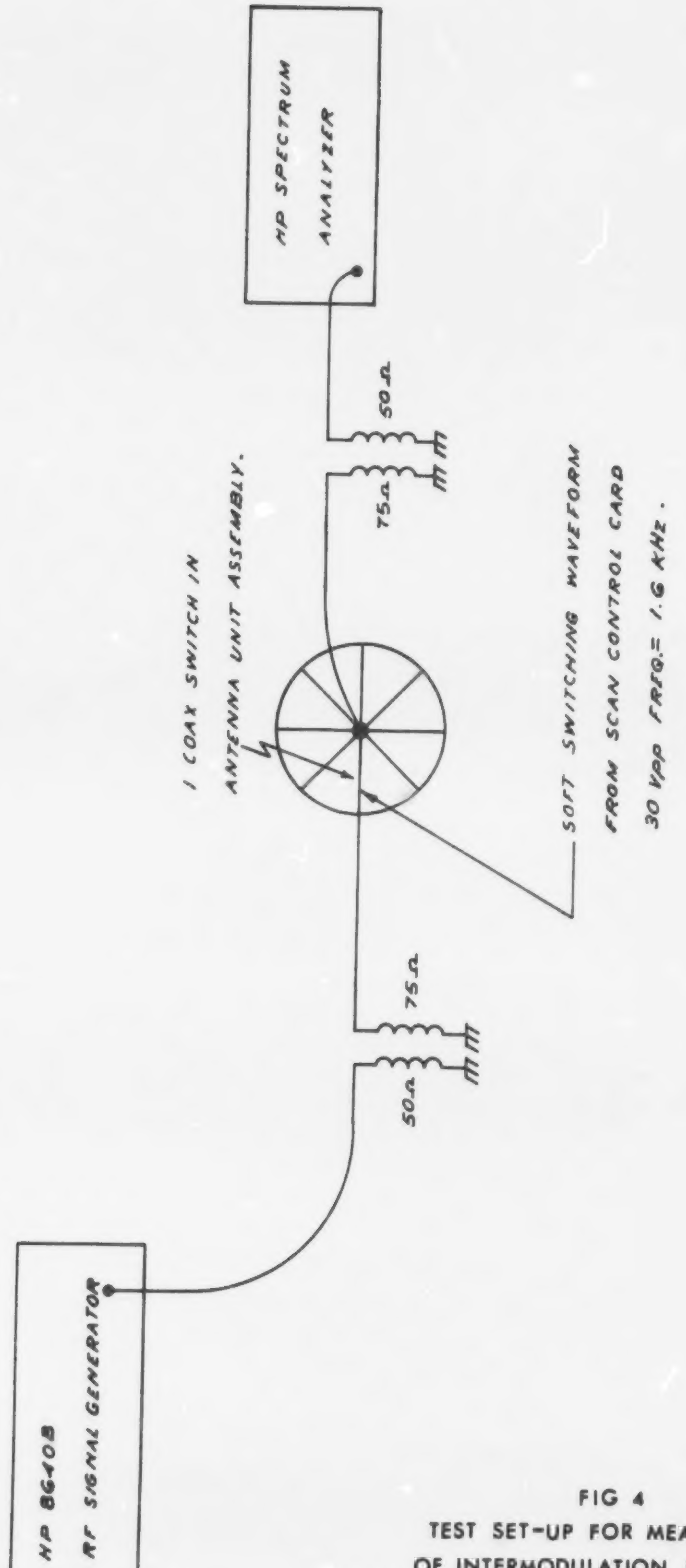

HP SPECTRUM ANALYZER
50Ω
75Ω
1 COAX SWITCH IN ANTENNA UNIT ASSEMBLY.
SOFT SWITCHING WAVEFORM FROM SCAN CONTROL CARD 30 Vpp FREQ.= 1.6 KHz.
75Ω
50Ω
HP 8640B RF SIGNAL GENERATOR

FIG 4
TEST SET-UP FOR MEASUREMENT
OF INTERMODULATION DISTORTION

With the phase balance in normal condition, the injection of a test signal results in a blank-out of the bearing readout and the signal overhead light comes on. A bearing can be displayed only by introducing differential phase modulation between the two receiver channels. This is accomplished by a software program in a microprocessor following the phase detector. The relative start of the phase modulation (45° or 315°) is set by pressing the appropriate test push-button. The amplitude of the phase modulation is set to ±120° peak-to-peak, corresponding to reception of a horizontally propagated wave. Any fault in the DF system from the dipole array to the bearing display inclusive will show as a distortion of the phase-detector waveform, resulting in an error shown on the bearing display.

To test the signal overhead condition, a test signal is injected and one of the phase modulation patterns is introduced, as in the DF System Test, but the amplitude of the phase modulation is reduced just below the limit corresponding to the 60° elevation of the target (±60° peak-to-peak of phase modulation). This activates the signal overhead indicator and alarm.

Maintenance Routines

The Phase Balance Test push-button gives a simulated signal source for installation check, DF system alignment and for any maintenance checks and trouble-shooting. The tests are performed with the aid of a simple two-channel Oscilloscope, set to display a single cycle of the scan frequency and triggered by the North pulse of the scanning system. The following test are considered as regular routines:

1. Applying channel 1 of 'Scope to the output of the phase detector shows a series of sixteen flat-top pulses of equal amplitude, near the d.c. zero line. The displacement of the pulse-top average from the d.c. zero gives a measure of any phase unbalance in the DF receiver channels or in the phase detector allowing for alignment of the appropriate sections.

2. Any "wiggles" in the above waveform (e.g. one step up, one step down) show a defective dipole or dipole switch. The dipole number can be established by counting from the North pulse reference.

3. Applying the 2nd channel of the 'Scope to the Integrator output, the relative position of the sampling window can be examined (expand the scan width as required) and adjustments can be made to the scan frequency delay and North pulse delay.

4. Pressing one of the system test push-buttons, instead of the phase balance test, will show test 3) above repeated with the phase modulation present. Inversions of the phase detector will show wherever the phase pulses exceed the ±130° limits.

Future Prospects

It is conceivable that the bearing processor can be expanded in the future to give a digital indication of the dipole phase matching (and/or fault) and of the DF receiver channel balance. Changes required for this expansion are too extensive to be incorporated in the prototype under construction.

Z.A. KRAJEWSKI

APPENDIX 8

TECHNICAL DESCRIPTION

APPENDIX IIA

TECHNICAL DESCRIPTION

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TECHNICAL DESCRIPTION

1.0 GENERAL SYSTEM DESCRIPTION

1.1 Introduction

The Bayly DF system for ATC is designed on the Quasi-Doppler principle, measuring the phase difference between successive dipole pairs scanned around a symmetrical circular array. The signal samples are amplified by a matched pair of receiver channels and applied to a linear phase detector which produces a stepped phase waveform synchronized to the scan frequency. A digital bearing processor examines the phase waveform and applies Fourier analysis to compute the phase and amplitude of its fundamental component frequency. This phase angle, related to the North reference is a measure of the bearing of the incoming radio signal. A simplified block diagram of the system is shown in Fig. 1-1.

1.2 Principle of Operation

In the original Doppler type Radio Direction Finder, an antenna element was rotated around a horizontal circle, and its output was connected to a tuned radio receiver provided with a frequency discriminator. Movement of the antenna towards, or away from, the radio target resulted in an apparent cyclical change of the received frequency shown as frequency modulation of the received carrier. A positive zero crossing of the FM output was shown when the antenna element was traversing the azimuth line of the target.

The Bayly Quasi-Doppler DF system employs no moving parts, and the antenna rotation is simulated by the switching of a number of antenna elements (e.g. 16) arranged symmetrically in a circular array. Instead of frequency, a phase difference is measured between two adjacent dipoles, resulting in a waveform of sixteen steps superimposed on a sine wave of the scan frequency. The phase difference of the outputs of a pair of antenna elements becomes zero when the pair is facing the target transmitter. This corresponds to the zero crossing of the fundamental (sine wave) component of the output waveform.

The zero crossing, and hence the bearing of the target, is computed digitally by carrying out a Fourier analysis of each set of samples comprising a full scan of rotation. Consecutive scans are further processed and averaged to improve the signal to noise ratio. The final bearing figure is displayed on a four-digit LED indicator.

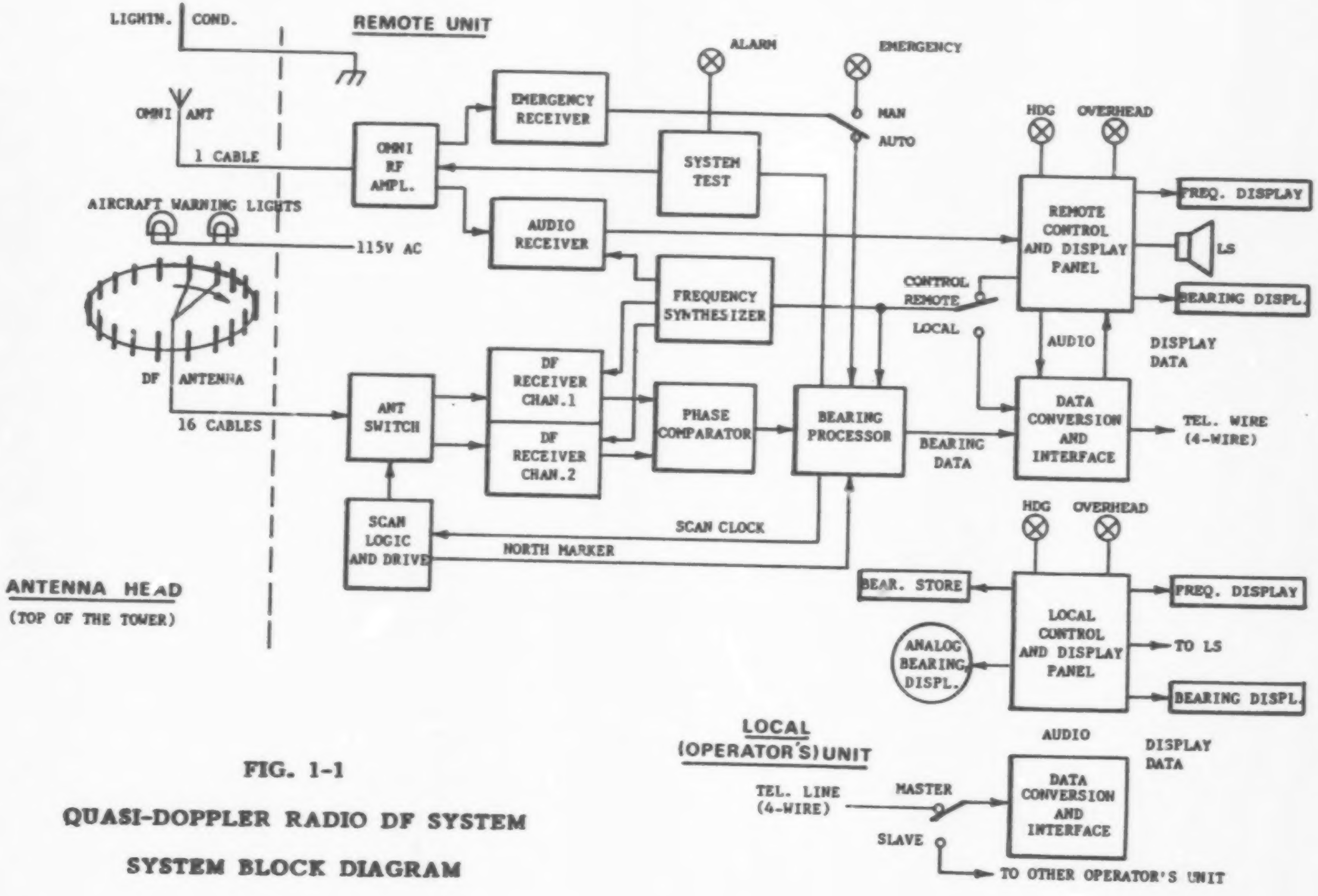

LIGHTN. COND.
REMOTE UNIT
OMNI ANT
1 CABLE
AIRCRAFT WARNING LIGHTS
115V AC
DF ANTENNA
16 CABLES
ANTENNA HEAD
(TOP OF THE TOWER)
OMNI RF AMPL.
EMERGENCY RECEIVER
AUDIO RECEIVER
SYSTEM TEST
ALARM
EMERGENCY
MAN
AUTO
FREQUENCY SYNTHESIZER
ANT SWITCH
DF RECEIVER CHAN.1
DF RECEIVER CHAN.2
PHASE COMPARATOR
BEARING PROCESSOR
BEARING DATA
SCAN LOGIC AND DRIVE
SCAN CLOCK
NORTH MARKER
CONTROL
REMOTE
LOCAL
HDG
OVERHEAD
REMOTE CONTROL AND DISPLAY PANEL
FREQ. DISPLAY
LS
BEARING DISPL.
AUDIO
DISPLAY DATA
DATA CONVERSION AND INTERFACE
TEL. WIRE (4-WIRE)
HDG
OVERHEAD
BEAR. STORE
LOCAL CONTROL AND DISPLAY PANEL
FREQ. DISPLAY
TO LS
ANALOG BEARING DISPL.
BEARING DISPL.
LOCAL (OPERATOR'S) UNIT
AUDIO
DISPLAY DATA
TEL. LINE (4-WIRE)
MASTER
SLAVE
DATA CONVERSION AND INTERFACE
TO OTHER OPERATOR'S UNIT

FIG. 1-1

QUASI-DOPPLER RADIO DF SYSTEM

SYSTEM BLOCK DIAGRAM

All the display and control functions of the system are digital. They are converted to a data stream of 400 Baud and applied to a voice and data modem which allows simultaneous transmission of voice and data over a 4-wire standard telephone line to the local (operator's) Control/Display Unit. The voice channel is normally that of an omnidirectional audio receiver tuned to the same channel as the DF system. Alternatively, it can be used as a maintenance telephone link between the local and remote stations.

1.3 System Configuration

Designed for fixed, land-based installation to operate in the Air Traffic Control band of 117.5-137.0 MHz, the system comprises a stationary circular antenna array, a remote receiver unit located in a shelter, and a local display/control unit at the console of the Air Traffic Controller. The antenna and the receiver unit are connected with a set of 17 RF cables. The receiver is linked to the display/control unit by means of a standard 4-wire telephone line.

The direction finding facility is supplemented by two optional features:

(1) Facility to demodulate the VF intelligence of the incoming signal (AM detector) and to transmit it to the display/control unit.

(2) Emergency call detection, monitoring on 121.5 MHz to indicate the presence of an emergency call, or to override temporarily the normal operation of the system in order to show the bearing of the distress transmitter.

Both the audio and the emergency receivers operate from an omnidirectional antenna, independent of the DF array and immune from its interference.

1.4 System Test Facility

A built-in system test provides the operator with an instant operational check out of the DF system. An internal test signal is generated at the tuning frequency which allows the system performance to be analyzed for correct operation and an alarm is activated in the case of failure of one or more of the constituent parts of the system.

1.5 Specification Summary

1.5.1 DF System

Frequency Range	: 117.5 - 137.0 MHz (civilian air traffic control) VHF.
Principle of Operation	: Large aperture Quasi-Doppler with differential sampling of 16 antenna elements.
System Accuracy	: ±3° max. bearing error measured in an obstruction-free site at a field strength of 5 µV/m to 50 mV/m.
Polarization Error	: ≤2° with 45° tilt of transmitter antenna.
Sensitivity (vertical polarization)	: 5 µV/m for ±1° or less of noise flicker
Group Delay Error	: Cancelled out by digital processing
DF Receiver Phase Match Error	: Cancelled out by bearing processor
Mode of Operation	: Continuous, unattended
Number of Frequency Channels	: Emergency channel plus 10 switch-selected channels - each channel frequency programmable within the equipment; plus option of a full range of 720 channels, operator selectable by pushbutton dialing.
Channel Spacing	: 25 kHz
Acceptance Bandwidth	: ±8.5 kHz
Adjacent Channel Breakthrough	: ≤3° error with adjacent channel signal up to 30 dB above wanted signal but not exceeding 50 mV/m.
Bearing Indication	: LED display numerals blanking out at no signal unless connected to store; display at both local (3 digits) and remote units (4 digits). Analog display circle of LED's in 5° steps at Operator's Panel only (local unit).

Response Time : 200 ms to 2.0 sec., depending on the signal strength which automatically controls the integration constant.

Bearing Readout Update : Equal to integration constant.

Valid Display Indication : Inaccurate bearings fluctuating by more than ±10° are blanked out.

Operator Panel Controls : Power On/Off; dimmer lamp test; channel select (pushbutton and indicator light) Heading/Bearing; store On/Off with indicator; remote control indicator; system alarm indicator; signal overhead indicator; frequency select mode and reset.

Receiver Panel Controls : As above, except no store On/Off and indicator. In addition, squelch On/Off, synthesizer phase lock indicator, RF agc level indicators, PS indicators.

Auxiliary Data Output : At both local and remote units, TTL compatible parallel data bit format.

Auxiliary Channel Select : At the remote unit for control from another site.

Squelch Threshold : Fully adjustable from front panel of remote.

Service Telephone : Jacks provided for 2-way communications between remote and local units (audio channel disabled).

Aircraft Warning Light : Integrated with antenna structure (may be left out if not required).

Cables

Antenna Head to Remote Receiver : 17 coaxial double-shielded ¼ inch cables, standard 50 ft. RF connectors, N-type.

Remote to Local : 4-wire telephone line, 3 kHz BW.

Audio Monitoring Facilities

Omni-directional Antenna : Centre of the Array.

Frequency : Automatically tuned with the DF System.

Type of Detector : AM

Output : : 0.5W loudspeakers on both remote and local units.

Auxiliary Output : 50 mW at 600 Ohms on the local unit.

Squelch : Provided on Remote Unit.

AGC : Provided on Remote Unit

Volume Control : Provided on both Local and Remote Units.

Emergency Receiver Facility

Antenna : Common with audio monitoring provided with separate filter.

Tuning : Set at 121.5 MHz

AGC : Pre-set

Detector : Carrier presence above threshold pre-set at the Remote Unit.

Auto/Manual Selection : At both Local and Remote Units.

Test Facilities

System Test (Local and Remote) : 2 pushbuttons: 45° and 315°. Checks antenna elements, DF receiver, bearing processor and display.

Overhead Test (Local and Remote) : Pushbutton, checks signal OH condition.

Test Generator : Remote receiver panel generates RF signal for maintenance purposes.

Alarm (Local and Remote) : LED indicator and audio beeper activated by failure in system test or in the voice and data transmission. Alarm reset pushbutton provided.

DF Receiver AGC : Remote receiver panel - manual switch for maintenance checks.

Test Points : Front panel access to receiver (remote unit) for inputs and outputs of all modules.

Environmental Conditions

Temperature Range Operational

Antenna : -55°C to +55°C

Local and Remote Unit : -20°C to +55°C

Humidity : 95% max.

Wind Load (Antenna) : 160 Km/hr max.

Salt Spray (Antenna) : Equivalent to MIL specifications

Drip-proofing (Antenna) : Equivalent to MIL specifications

Ice Formation (Antenna) : Up to 2 inch thickness.

1.6 Functional Sub-systems

For the purpose of a detailed description, the system is considered as a series of functional sub-systems, each performing a different function which can be technically defined in terms of cause and effect, or inputs and outputs. In this concept, a functional sub-system is not necessarily confined inside a single piece of equipment, but may be divided into several sections housed in different units.

Eight such functional sub-systems can be clearly separated in the Quasi-Doppler Radio Direction Finder System:

i Antenna Array with Dipole Commutation

ii DF Receiver

iii Bearing Processor

iv Control and Display Circuits

v Audio and Data Transmission

vi Omni-directional Monitoring Receivers

vii System Test Facilities

viii Power and Interface

2.0 ADVANTAGES OF THE DESIGN CONCEPT

2.1 Introduction

Doppler DF Systems have been used successfully for over 40 years, over several generations of design approaches and stages of technology. What distinguishes the present System can be summarized in the following points:

i Ultra-stable antenna structure of 'bicycle wheel' concept.

ii No semiconductor or active components in the top mast location.

iii 'Soft-switching' technique of dipole commutation.

iv Two-channel sampling of the array dipoles.

v Linear Phase Detector with over-swing capacity.

vi Processing the bearing by Fourier analysis.

vii Compensation for site errors.

ix Separate audio and emergency receivers (optional).

x Audio and data transmission over standard telephone line.

xi Built-in system test.

2.2 Antenna Structure

The antenna array, consisting of 16 dipoles and an omni-directional centre element, is supported by a mechanical structure resembling a bicycle wheel with a rigid, insulated rim and a network of criss-crossed steel cables, or 'spokes', which form a conducting ground plane. Vertical support is provided by a set of insulated radial struts which restrict any flexing of the array plane. This type of structure has an inherent rigidity and mechanical stability under all conceivable wind and ice loading conditions. For given precision of relative dipole positions, this design was proven lighter and easier to construct than other ways of construction.

2.3 The antenna dipoles are connected directly to the Receiver Unit by means of a set of low-loss coaxial cables. The dipole switching, and the subsequent amplification and processing, are all carried out inside the remote receiver unit located in the shelter.

2.4 Soft-Switching Technique

The 16 antenna dipoles are selected in pairs by means of pin-diode switches operated by control pulses of the scan-logic system. Such commutation normally produces an infinite series of mixing products which appear as side-bands of the received carrier. In this design, the higher order mixing products are reduced by using 'soft' control pulses of special waveform which make the switch attenuate in the critical changeover period. As a result, it is possible to receive a bearing from a weak signal with an interfering signal 30 dB higher in the adjacent channel, i.e. 25 kHz away.

2.5 Two-Channel Sampling of Phase

By sampling two instead of one dipole, the restrictions are removed on the aperture of the array - there being no ambiguity of bearing as the diameter becomes larger than the wavelength. The same system design may be used with different sizes of arrays, say with 8 elements, 16 or 32 elements.

Speed of commutation is not critical. There is no need to ensure a frequency deviation large enough in comparison with the stability of the carrier. The only criterion is that of the bearing response time. A rotation frequency of about 100 Hz provides a bearing reading averaged over 8 cycles in 0.1 second. A low commutating frequency has the advantage of less interference with the audio reception. Furthermore, the splash-over of intermodulation products into the adjacent frequency channels is also reduced.

The two i.f. channel voltages are similar in amplitude and contain equal percentages of AM or FM and an equal share of atmospheric noise and of the noise of the local oscillators. By measuring their relative phase, any modulation or noise effect is reduced to negligible proportions. The phase comparator operates throughout each period of dipole pair sampling so that there is minimum waste of real time in receiving the signal. It is the cyclical waveform of the phase output which contains the azimuth information.

2.6 Linear Phase Detector

A large antenna aperture, needed to provide immunity from field site errors, makes it necessary to measure a range of phase differences of up to ±180°. This makes it impractical to use a conventional phase detector with sinusoidal characteristic. For this reason, a linear phase detector was adopted, converting the phase difference between the two receiver channel outputs to pulse-width modulation, followed by an integrating network. Phase angles exceeding ±180° can still be detected by instantly reversing one of the channel inputs by 180° and then correcting the reading in the software section by adding or subtracting the 180° constant.

2.7 Fourier Analysis

The cyclical waveform of the phase output contains a number of components which have to be separated and identified:

- i A zero offset due to group delay and the phase unbalance of the twin-channel DF receiver and phase detector sub-system.
- ii The fundamental scan frequency, the phase of which relative to 'North' is a measure of the DF bearing.
- iii Harmonics of the scan frequency due to combined reflections of other dipoles, the support structure and miscellaneous field site effects.
- iv Phase jitter noise due to interference of either atmospherics or system noise or the effect of presence of other signals of different frequencies.

Processing the bearing by Fourier analysis secures the information of item ii) (phase of the scan frequency) and rejecting the others. The computed bearing is obtained much faster than would be possible by using an analog filter tuned to the scan frequency. Furthermore, the group delay of such a filter is no longer a source of possible error.

2.8 Frequency Synthesizer

In the older generations of Doppler DF Systems, it was conventional to select a limited number of frequency channels by switching crystal oscillators. The modern approach is to use a frequency synthesizer, phase locked to a master crystal oscillator, and tuned in steps by means of digital programming. In the Bayly DF system, there is provision for 11 pre-set channel frequencies, and also for direct dialing of any frequency channel within the ATC band. Ten of the pre-selected channels can be manually set to the desired frequency by means of DIP switches inside the equipment. The 11th channel is permanently set to the emergency frequency of 121.5 MHz.

2.9 Compensation for Site Errors

The large antenna aperture (1.5 wavelength for a 16 element array) used in this system ensures that the effects of field site reflections are relatively small, as can be demonstrated by moving a car or metal object in the vicinity of the DF tower. However, a further step was taken to reduce the field site errors by introducing appropriate bearing corrections in the software of the bearing processor sub-system.

The procedure is to calibrate the bearing errors for a full circle of azimuth of a target transmitter and to enter a correction chart into the microprocessor software. This correction is accurate to the extent of the stability of the field site error, i.e. it still remains subject to minor fluctuations, due to weather changes and the position of mobile objects and their frequency of resonance. The microprocessor memory allows for corrections every 5° over, up to five frequency bands in the RF input range.

2.10 Separate Audio and Emergency Channel (optional)

A separate omni-directional antenna, located at the electrical centre of the array is connected to a separate receiver channel tuned to the same frequency as the two Doppler channels. The i.f. portion is provided with AGC and connects to an AM demodulator. Re-radiation of the commutation pulses from the DF dipoles is reduced by keeping this antenna separate and somewhat elevated with respect to the plane of the array. The audio output of this receiver can be monitored in the remote unit, and is further available for transmission to the local unit.

Since the FM cancellation for DF no longer depends on the signal from the centre antenna, the entire audio channel can be left out if this facility is not required.

Emergency call signals at 121.5 MHz are monitored by the centre antenna and processed via a separate emergency receiver with fixed tuning, terminating in a detector, the output of which responds to the emergency condition.

Two modes of Emergency Channel are provided:

Mode 1 - Fully Automatic

In the auto position, the detection of an emergency signal automatically allows the Direction Finder to determine a bearing and to transmit bearing data to the local site. In addition, an emergency status signal is transmitted to the local site where it illuminates an emergency indicator and sounds an audible alarm at both local and remote sites. A long release time constant ensures that the alarm remains locked even on pulsed signals. This override function will revert to normal at the end of the emergency call.

Mode 2 - Manual

In this mode, the MAN-AUTO switch is placed in the MAN position. Upon detection of an emergency signal, an emergency status signal is transmitted to the local site to illuminate the emergency indicator and sound the audible alarm. The operator may then, at his discretion, operate a switch to select the emergency channel frequency.

2.11 Interconnections and Audio and Data Transmission

The Antenna Head is connected to the Remote Unit by means of a set of 17 coaxial cables. The length of this connection is of the order of about 50 ft. for a standard installation at the airport.

A complete set of data-above-voice modems is built into the system to provide a facility for remote control from one or more locations.

The Remote-Local link consists of a standard telephone wire quad, in the form of a buried cable. C1 grade characteristics are advisable to avoid losses at the data transmission frequencies. Up to 10 Km distance is envisaged which can be extended by the addition of standard telephone repeaters. An alternative Local-Remote link for short distances up to 100 m would consist of a multi-core control cable with the omission of the 'data-above-voice' modems.

2.12 A built-in system test allows the operation to instantly verify whether the system is fully operational. On depression of a 'System Test' pushbutton, an internal test signal is generated at the frequency or channel to which the set is tuned. This signal is applied to the omnidirectional (central) antenna element, creating a series of scan pulses at the output of the DF receiver. The pulses are processed and analyzed by the Bearing Processor to give an indication of the test bearing, and to sound an alarm if any part of the system does not perform with the expected accuracy.

3.0 ANTENNA ARRAY AND DIPOLE COMMUTATION

3.1 Introduction

The Doppler antenna consists of a number of vertical dipoles tuned to the top of the frequency band and spaced equally in a circle. All the dipoles are connected with equal length cables to the commutator located in the Remote Unit in the shelter. Two adjacent dipoles are sampled simultaneously, the pair being switched round the circle at a rate set by the commutation generator. The voltages induced in the sampled pair remain almost constant but their relative phase undergoes cyclical variation as the switching progresses through 360 degrees. This phase can be measured continuously after the signals are processed through two identical receiver channels, each consisting of RF amplifiers, frequency converters and i.f. stages.

The Phase Comparator operates at the final intermediate frequency and produces an output of a stepped waveform superimposed over a sine function, each step corresponding to a different pair of dipoles. It is the positive-slope zero crossing of this waveform which determines the angular position of the target.

The DF antenna sub-system is shown on the block diagram of Fig. 3-1. It can be sub-divided into three sections:

- the dipole array
- commutation network
- scan logic control

The commutation network and the scan logic are contained in the Remote Unit, installed in a shelter underneath the antenna tower.

3.2 The Dipole Array

The prototype developed for the ATC has 16 dipoles with a wide tuning range of 115 MHz - 140 MHz. They are spaced at approximately 120° maximum phase difference (1/3 of the wavelength) at the highest signal frequency. The dipoles are mounted at the extreme points of a star-shaped artificial ground plane made up of a mesh of stainless steel tension cables. The ground plane is continued on the outside of the array with a set of 16 horizontal counterpoise rods, balancing the polar pattern of horizontally polarized waves around each dipole. Dipoles are connected to the switching network with a set of 50 Ohm coaxial cables matched to the same electrical length with an accuracy of a fraction of a degree at the highest frequency in the RF band.

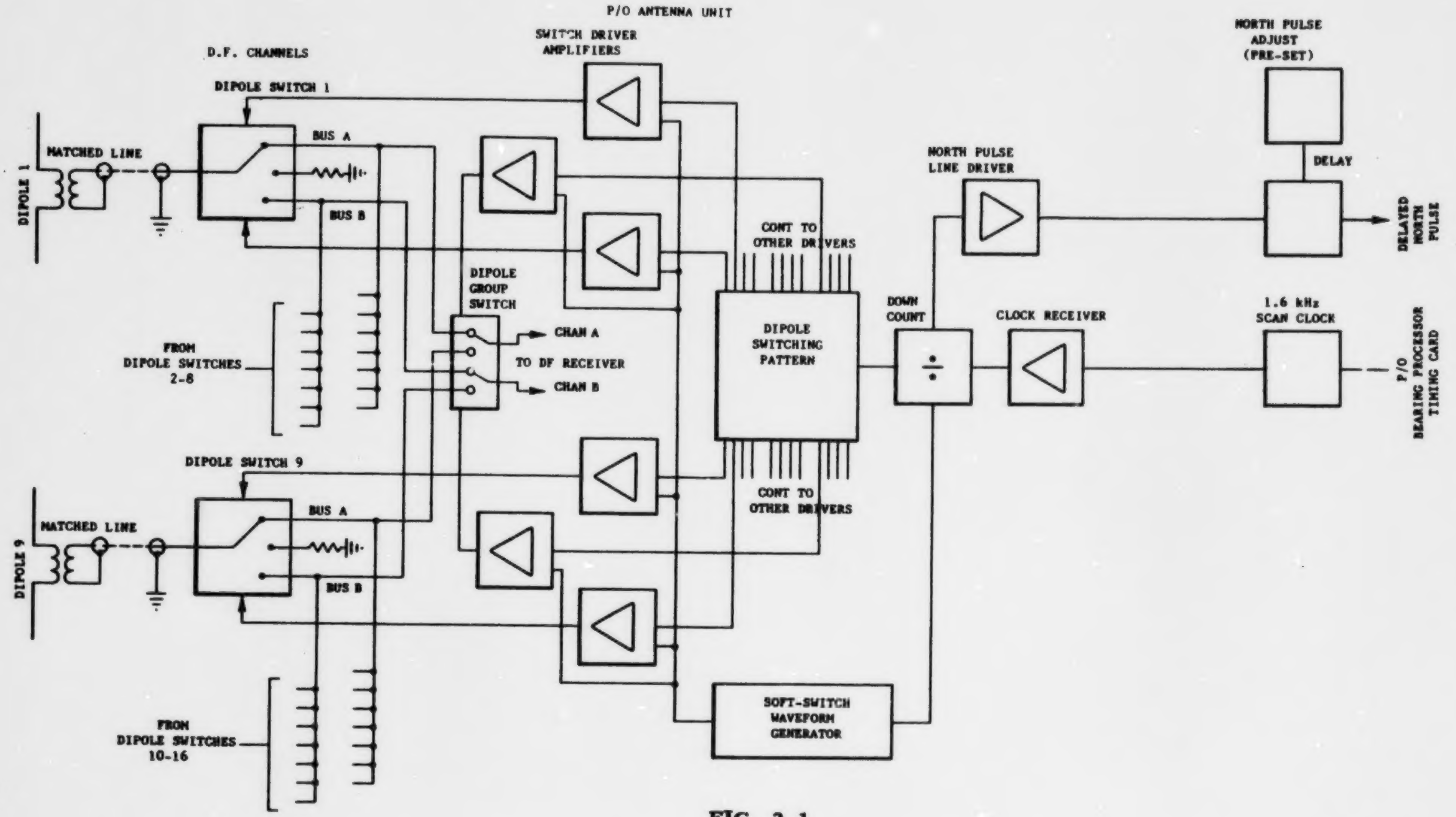

P/O ANTENNA UNIT
SWITCH DRIVER AMPLIFIERS
D.F. CHANNELS
DIPOLE SWITCH 1
DIPOLE 1
MATCHED LINE
BUS A
BUS B
DIPOLE GROUP SWITCH
CHAN A
TO DF RECEIVER
CHAN B
FROM DIPOLE SWITCHES 2-8
DIPOLE SWITCH 9
DIPOLE 9
MATCHED LINE
BUS A
BUS B
FROM DIPOLE SWITCHES 10-16
CONT TO OTHER DRIVERS
DIPOLE SWITCHING PATTERN
CONT TO OTHER DRIVERS
SOFT-SWITCH WAVEFORM GENERATOR
DOWN COUNT
NORTH PULSE LINE DRIVER
CLOCK RECEIVER
NORTH PULSE ADJUST (PRE-SET)
DELAY
DELAYED NORTH PULSE
1.6 kHz SCAN CLOCK
P/O BEARING PROCESSOR TIMING CARD

FIG. 3-1

ANTENNA ARRAY AND DIPOLE COMMUTATION

SUB-SYSTEM BLOCK DIAGRAM

The dipole design incorporates a unique lightning protection feature - a short-circuiting centre rod of a length corresponding to ½ wavelength for the band of frequencies in use. This rod is firmly bonded at the centre to the ground plane of the array. Additional corona protection is provided by placing neon lamps across each dipole element.

The mechanical structure supporting the dipoles relies on a non-metallic ring, suspended from the mast by means of a number of non-metallic rods above and below the centre line of the ring. An array of metallic cables in the centre line of the ring places the ring in tension and, at the same time, provides the necessary ground plane for the antenna. Precision springs on one end of all the rods and cables ensure correct pre-tensioning of all the structural members during installation, without the need for any complex tension-measuring devices. They also ensure stability of the structure under temperature and ice loading stresses, making it possible to maintain the relative symmetry of the dipole array to better than 0.02° of the bearing angle.

3.3 Commutation Network

Sequential switching of the dipole pairs onto a pair of DF receiver channels requires that each dipole be provided with a coaxial 3-way switch so that it can be linked to either Channel A or Channel B of the receiver, or to a dummy load when not actively engaged. The pair sampling proceeds at a rate approximately 660 ms per step, giving an array scan frequency of approximately 100 Hz.

The outcome of this sequential sampling produces, from each dipole, an RF signal which is interrupted at the rate of the scanning frequency, i.e. a pulse modulated signal. This signal, therefore, is made up of the fundamental RF frequency in addition to the upper and lower sidebands of all the components of the switching frequency. These additional products can extend over a bandwidth covering several hundred kHz, creating interference on a large number of adjacent channels and resulting in severe degradation in DF performance. This is avoided in the Bayly design, where the switching action is accomplished with a special waveform of low zero slope. In such a 'Soft Switch', there are fewer high order products, thus reducing interference from adjacent channel transmissions.

The 3-way 'Soft Switch' is made up of PIN diodes which can be considered as variable RF resistors whose resistance is inversely proportional to the forward current. By employing these diodes in a (T) configuration, it was possible to construct an RF switch having an attenuation which is directly controlled by the shape of the driver waveform. In this circuit, the largest change in attenuation occurs during the first few milliamperes of current through the diodes. This implies that the first volt of bias will have the greatest impact on the performance of the switch.

Therefore, it follows that, in order to reduce the generation of unwanted IM products, the slope of the input drive voltage must be kept as low as possible. To obtain this effect, a special waveform was generated by driving a triangular signal through a network consisting of diodes and resistors. The slope at the diode's knee is used to provide soft switching for both the on and off conditions, with minimum slope occurring at the transition region. The shape of the centre portion of the driving pulse is simply squared off to give the 'full on' condition.

The 16 dipole selectors are arranged in two sets of 8 in order to reduce the shunt loading of the unused sections. Each set of 8 handles a semi-circle of the antenna array and, in turn, the appropriate semi-circle is chosen by a four-sector switch connected in cascade, making up the total number of switch boards to 20. The switches are driven by push-pull driver circuits, mounted 4 to a card, thus making a total of 5 driver cards. The drivers take their inputs from the scan logic control which determines the sequence of operation of the dipoles.

The commutator design is fully modular, and its component sections can be easily adapted to construction of an 8 element or 32 element system.

3.4 Scan Logic Control

Antenna array scanning is controlled by a frequency derived from a clock which is part of the bearing processor. The clock frequency is counted down and shaped into a triangular wave, which is then modified into the special 'soft switching' waveform used to drive the dipole switches. The switch selection is dictated by reference to a PROM contained on the scan logic card.

Every time the scan makes a full circle, a reference pulse is generated, called the 'North Pulse' which is applied to the bearing processor as reference for the computation of bearing. The North Pulse generated on the scan logic control board is positioned half-way through the engagement period of dipoles 1 and 16. When arriving at the bearing processor, it undergoes two modifications:

i It is delayed by a time equal to the group delay of the DF receiver.

ii Its timing is further corrected by a manual DIP switch which allows a minor adjustment to be made of the true 'North' position relative to the mechanical 'North' of the antenna array.

3.5 Sub-System Specification, Antenna Array and Commutation

Antenna Array

Frequency Range : 117.5 - 137.0 MHz

Number of Dipoles : 16 with N-type connectors

Diameter of the Array : 1.7 wavelengths at max. frequency

Dipole Impedance : 70 Ohms single-ended at mid-range, VSWR ≤ 2 over the entire band

Dipole Protection : Internal short-bar, $\lambda/2$ resonant at mid-range. Additional corona protection with neon tubes

Dipole Antenna Factor : 6 dB approximately

Dipole Feed Cable : 50 Ohm coaxial low loss type (all feed cables to be matched in phase to within 1°) and connected to the switches with N connectors

Dipole Mounting Accuracy : 0.02° w.r.t. mast axis

Dipole Replacement : Individually removable from the outside of the support ring

Ground Plane : 16 point star of stainless steel cables bonded at points of crossing

Ground Counterpoise (each dipole) : Radial, horizontal rod of 3/8 wavelength approximately

Coarse 'North' Setting : By rotating mounting plate during installation (adj. steps of 11.75°)

Commutation Network

Dipole Selection : One pair of adjacent dipoles, scanned periodically in 16 steps in clockwise direction viewed from the top

4.0 DF RECEIVER SUB-SYSTEM

4.1 DF Receiver Concept

The two signals obtained from scanning the dipole pairs in the antenna array are amplified by two identical receivers and applied to a phase detector. This is conventionally called a 'two-channel' receiver where the meaning of 'channels' are the signal paths rather than tuning frequency allocations.

To be able to perform the phase measurement accurately, it is essential to design the receiver so that its corresponding channel sections are matched exactly to one another, both in gain and in phase, over a wide range of signal conditions and environmental factors. The underlying principle is to make the two channels with identical circuits, layouts and component values, and to align them to match section by section.

The DF receiver for the Quasi-Doppler system has to satisfy the requirements of the low noise factor, adjacent channel selectivity and constant output over a wide dynamic range. These conditions are commonly expected from a conventional FM receiver. However, the twin-channel, i.e. receiver sub-system, also requires the phase and gain matching facilities and a group delay which is constant over the pass-band, and as short as possible, while satisfying the bandwidth requirements. For common tuning, the two channels of the receiver must be fed from common local oscillators via phase-matched paths and through buffer stages with sufficient forward to back gain ratio to minimize interchannel crosstalk.

4.2 Frequency Plan and Filter Characteristics

The most critical part of the two-channel receiver are the band-pass filters used to select the wanted frequency channel and to reject any image or interference products. The phase-matching requirement limits the design of any individual filter to a maximum of 7 tuned circuits, five being preferable, for ease of alignment. To be able to utilize such filters, the DF receiver has three stages of frequency conversions. The last intermediate frequency of 200 kHz has been determined by the realization of a seven-circuit filter to accommodate the 17 kHz bandwidth required by stability of transmitters with the 25 kHz channel spacing. This filter is of Legendre's type, with a linear phase response in the centre ±3 kHz of the band, combined with very steep edge of the band cut-off.

The first i.f. of 30 MHz was taken as approximately 1.5 times the width of the VHF input band so that tuning can be accomplished with a single sweep of the local oscillator without range switching of the VHF input filters. The input filters are divided into two sections.

Termination of Unused Dipoles : 50 Ohms, located on the switch assembly

Dipole Switch Network : 2 sets of 8, 3-way switches, in turn selected by a set of 4

Scan Frequency : 100 Hz approximately

Switch Action : 'Soft Switching' with special waveform to reduce intermodulation on adjacent channels

Commutation Network Output : Two matched 50 Ohm cables with N connectors

Scan Logic Control

Scan Clock : 1.6 kHz supplied from the bearing processor

'Soft Switch' Waveform : Generated from the scan clock with a dual slope reduction circuit

Switching Program : 40 outputs (TTL Level) to control the push-pull drivers of the dipole switches. Self contained PROM

North Reference : 'North' pulse generated from the scan clock in the mid-position of the switching time of the dipole pair 1-16. Output to bearing processor

Delayed North Pulse : Obtained in the bearing processor (timing card) to compensate for the group delay of the DF receiver and phase detector

True 'North' Adjustment : By pre-setting a binary DIP switch on the bearing processor timing card. Correction by software, min. ±10°

(1) A low-loss, two-stage pre-tuning filter to pass the ATC VHF band to reduce interference from the adjacent FM and amateur bands, as well as to cut off interference from secondary radar.

(2) A full r.f. five-stage band-pass filter, following the RF Amplifier with sufficient selectivity to suppress the local oscillator nd image frequencies.

The second conversion produces 2.2 MHz, which is close to the geometrical mean of the first and the third i.f. The filter bandwidths of the 30 MHz and 2.2 MHz i.f. filters were made just wide enough to suppress the respective first and second i.f. image frequencies with a minimum number of tuned circuits in each.

TABLE 1.4 - FREQUENCY PLAN OF DF RECEIVER

Input Band	LO$_1$ (freq. synth.)	IF$_1$	LO$_2$ (crystal osc.)	IF$_2$	LO$_3$ (crystal osc.)	IF$_3$
117.5-137.0 MHz	147.666.5 MHz	30MHz ±400kHz	27.8MHz	2.2MHz ±50kHz	2.4MHz	200kHz ±8.5kHz
Primary Image		1st i.f. Image		2nd i.f. Image		
117.5-196.5 MHz		26.6MHz		2.6MHz		

The above frequency plan is relatively free of spurious responses in the input band, with the exception of the fourth harmonic of the first i.f. (4 x 30 = 120 MHz). There is no significant pick-up of the 120 MHz spurious at the receiver input.

4.3 Receiver Input

The antenna switching network is mounted on top of the receiver unit and connects to the receiver with a matched pair of coaxial cables inside the cabinet.

4.4 DF Receiver Functional Block Diagram

The functional block diagram of the DF receiver is shown in Fig. 4-1, where it is combined with a chart of minimum and maximum levels at the interface points. The frequency conversion scheme and the bandwidths of the corresponding filters are shown in circles.

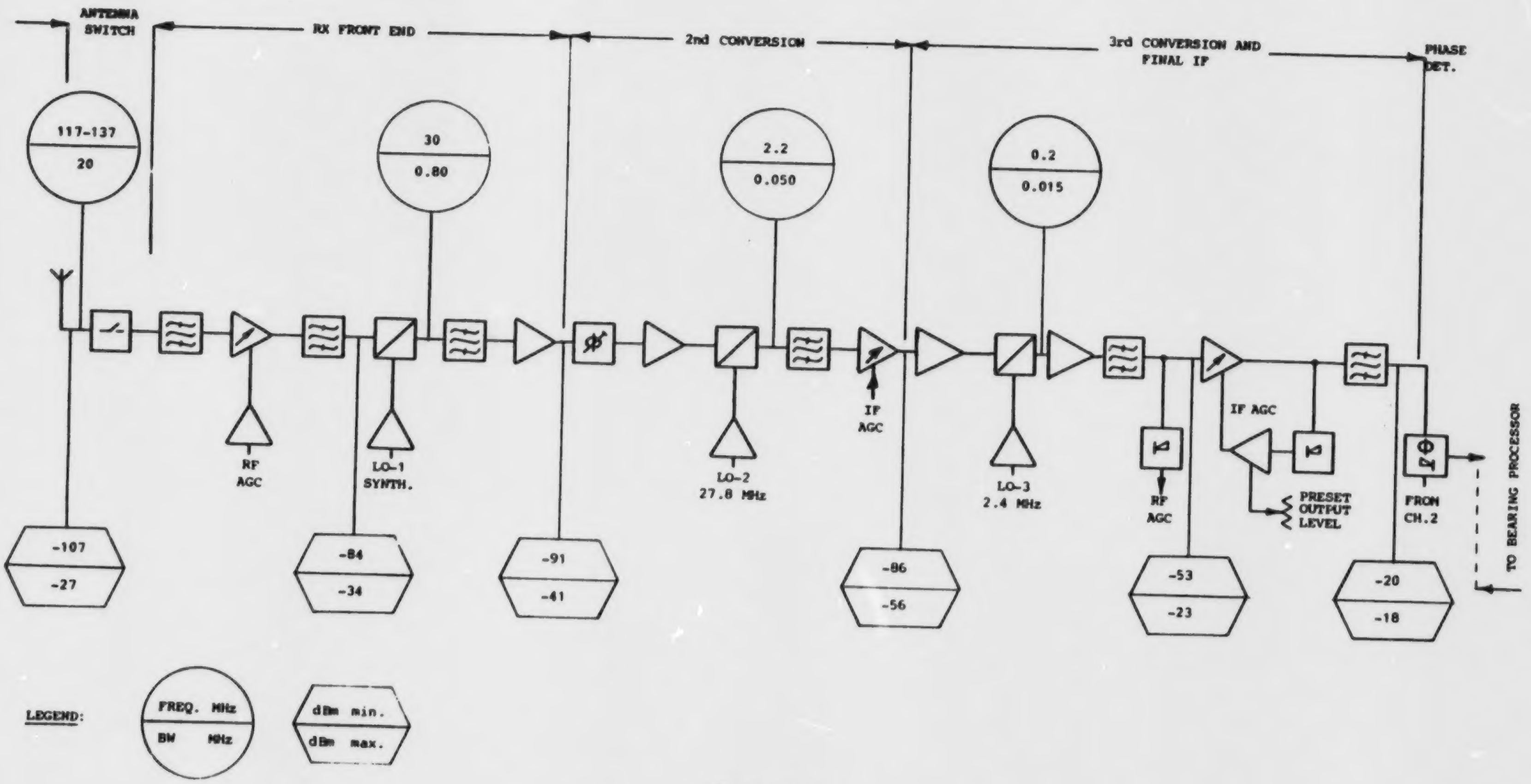

ANTENNA SWITCH
RX FRONT END
2nd CONVERSION
3rd CONVERSION AND FINAL IF
PHASE DET.
117-137
20
30
0.80
2.2
0.050
0.2
0.015
RF AGC
LO-1 SYNTH.
LO-2 27.8 MHz
IF AGC
LO-3 2.4 MHz
RF AGC
IF AGC
PRESET OUTPUT LEVEL
FROM CH.2
TO BEARING PROCESSOR
-107
-27
-84
-34
-91
-41
-86
-56
-53
-23
-20
-18
LEGEND:
FREQ. MHz
BW MHz
dBm min.
dBm max.

FIG. 4-1

DF RECEIVER FUNCTIONAL BLOCK DIAGRAM

(one channel only shown)

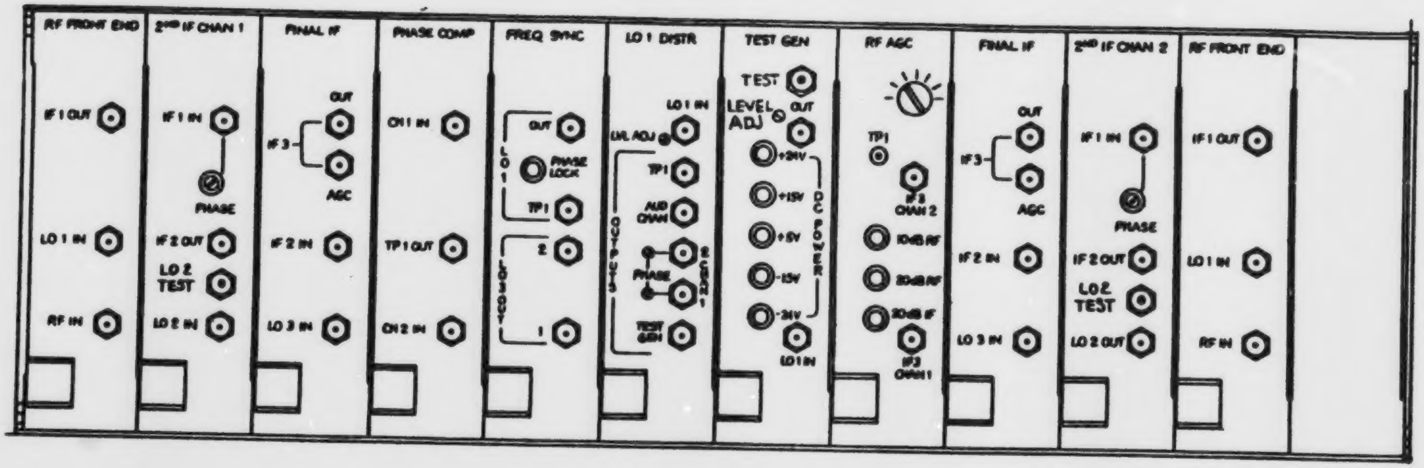

RF FRONT END
IF 1 OUT
LO 1 IN
RF IN
2ND IF CHAN 1
IF 1 IN
PHASE
IF 2 OUT
LO 2 TEST
LO 2 IN
FINAL IF
OUT
IF 3
AGC
IF 2 IN
LO 3 IN
PHASE COMP
CH 1 IN
TP 1 OUT
CH 2 IN
FREQ SYNC
LO 1
OUT
PHASE LOCK
TP1
LO 3 OUT
2
1
LO 1 DISTR
LO 1 IN
LVL ADJ
OUTPUTS
TP1
AUD CHAN
PHASE
CHAN 2
CHAN 1
TEST GEN
TEST GEN
TEST
LEVEL ADJ
OUT
DC POWER
+24V
+15V
+5V
-15V
-24V
LO 1 IN
RF AGC
TP1
IF 3 CHAN 2
10dB RF
20dB RF
20dB IF
IF3 CHAN 1
FINAL IF
OUT
IF 3
AGC
IF 2 IN
LO 3 IN
2ND IF CHAN 2
IF 1 IN
PHASE
IF 2 OUT
LO 2 TEST
LO 2 OUT
RF FRONT END
IF 1 OUT
LO 1 IN
RF IN

FIGURE 4-1-1

DF RECEIVER

4.5 DF Receiver AGC Network

Constant output of the two receiver channels is a necessary condition to make the phase detector perform accurately. For this purpose, the prototype is provided with two AGC networks - one in the r.f. section and one in the final i.f. stages. Thresholds of operation of the two networks are different. The i.f. AGC starts to function directly from the maximum sensitivity level and continues to control the receiver output down until the input level reaches 30 dB above the minimum. At this point, the r.f. AGC switches in, first with an attenuator pad of 10 dB, then with 20 dB and so on up to 50 dB to the maximum input of -27 dBm.

The i.f. AGC operates individually in each receiver channel at 200 kHz with an amplifier of continuously variable gain and a detector fed from its outputs, forming a self-contained loop in each of the two receiver channels. Its dynamic range is over 50 dB, leaving some margin for adjustment at the extreme ends of the range. Two adjustments are provided: the operating threshold and the loop gain.

The r.f. AGC detects the signal level after the 3rd conversion in channel 1 or 2 of the receiver (whichever is greater) but before the i.f. AGC loop. This signal is amplified and processed through a logic network to provide digital data for switching PIN-diode attenuator pads in the r.f. and 2nd i.f. stages. Identical attenuators are switched simultaneously in both the receiver channels. The main objective of the r.f. AGC is to keep down signal levels at the mixer inputs so as to avoid IM interference. There are threshold adjustments of the trigger action for the 10 dB and the two 20 dB pads respectively.

Both the i.f. and the r.f. AGC loops are activated by signals inside the fundamental 17 kHz tuning band of the selected frequency channel, hence they do not respond to adjacent channel interference.

4.6 Local Oscillators

All the local oscillators used for frequency conversion are common to the two channels of the DF receiver, and their feed points to the respective mixers are isolated with buffer stages to prevent crosstalk. In the DF receiver, there are three conversion stages and, therefore, three local oscillators are needed.

The first local oscillator (LO_1) is a frequency synthesizer with the VCO operating at a frequency 30 MHz higher than the r.f. input. Its output is divided down to 25 kHz which is fed back in the phase-lock loop. The tuning is accomplished by digitally controlling the number of the count-down, giving a total of 720 steps, one every 25 kHz.

The frequency synthesizer is contained in one module forming part of the receiver but the control network, including DIP switches for the preset channels, forms part of the Control/Display sub-system. The LO_1 tunes both the DF channels and the audio channel of the DF system. It also provides a component part of the test frequency used in the Test Generator function. Output of the LO_1 goes directly to the audio channel in the Receiver Unit and is further divided to feed the two DF channels and the test generator network. DF channel phase balance is provided in the Oscillator Distribution module, and individual buffers are located in the front-end modules of the DF receiver channels.

The second local oscillator (LO_2) operates at 27.8 MHz and is crystal-controlled, fitted with a varactor and an optional control line for AFC. LO_2 for the DF receiver is mounted inside one of the 2nd conversion modules. The emergency channel has a separate source of LO_2 - also a crystal controlled oscillator.

The third local oscillator (LO_3) serves a dual purpose: it provides oscillator frequency for the third conversion stages of the two DF receiver channels, and it serves also as the main reference frequency for the synthesizer phase-lock. It is located physically in the Frequency Synthesizer module.

4.7 Phase Detector

Constant amplitude outputs (approx. -20 dBm at 200 kHz) are applied from the two channels of the DF receiver to the input of a linear phase detector. The phase detector performs three consecutive functions: limiting and squaring, pulse-width modulation and integration combined with filtering out of the fundamental carrier wave. The detector has a linear range of 0°-360° which is normally shifted by an inverter to $\pm 180^\circ$.

Output of the phase detector, with signal present, is a picture of the scan waveform broken into 16 steps corresponding to the positions of the switching of the 16 dipole pairs. This waveform is applied to the bearing processor which is made to neglect the switching transients and to sample the amplitudes of the flat portions of the steps which provide a measure of the consecutive phase differences between the dipole pairs.

Phase inversion of one of the channels is controlled externally by a logic pulse from the bearing processor. This allows to extend the linear range of the phase detector in places where it is known that the phase difference approaches or exceeds the $\pm 180^\circ$ limit. The practical extended limit of linear operation is $\pm 230^\circ$ as explained later in the description of the Bearing Processor Sub-system.

The positive-slope zero crossing of the scan waveform shows the approximate bearing of the target taken with reference to the 'delayed North Pulse' test output. The amplitude of the waveform is nearly constant for horizontally propagated waves but it decreases if the target is elevated. The ratio of decrease is used to trigger the 'signal overhead' indication (60° elevation corresponds to 50% level of the amplitude).

The only maintenance adjustment of the phase detector is the zero offset of the output Op-amp which should be set to give zero volts DC with the two input lines shorted.

4.8 DF Receiver Specification

Principle of Operation	:	Two-channel receiver for measurement of phase difference
Frequency Range	:	117.5 MHz - 137.0 MHz
Tuning	:	Digital control by frequency synthesizer in steps of 25 kHz (10 lines, TTL Level)
Tuning Stability	:	±5 ppm over temperature range 0°C to +35°C
Input Impedance	:	50 Ohms, SMA terminals
RF Noise Figure	:	≤7 dB each channel
Dynamic Range	:	-107 dBm to -27 dBm
RF AGC	:	50 dB max. in 10 dB steps, -77 dBm threshold ref. to input common to both channels
Bandwidth	:	17 kHz (-3 dB), linear phase response over ±3 kHz from the centre of the band
Selectivity	:	80 dB at ±25 kHz
Output to Phase Detector	:	-20 dBm0 +3 dBm, both channels
Phase Match	:	±15° or better between the two receiver channels
Phase Detector Output	:	±6.0V for input of ±180°

Phase Detector Linearity : ≤1% over the range ±175°

Phase Reversal : Reversal through 180° at input to phase comparator, controlled from bearing processor (TTL Level)

Group Delay : 240 µs approx. receiver input to output of phase detector, but not varying by more than ±10% over the ±3 kHz bandwidth and 80 dB dynamic range

5.0 BEARING PROCESSOR SUB-SYSTEM

5.1 Design Concept

The purpose of the bearing processor is to compute the angle of arrival (the bearing) of the incoming signal, to evaluate it, and to send the result to a numeric display.

The input of the bearing processor is the phase waveform received from the phase detector of the DF Receiver. The bearing angle can be determined from this waveform with reference to a North pulse which is timed when the antenna scan crosses the North azimuth.

The complete process can be divided into three sections:

i) Data preparation, consisting of pulse sample and hold, A/D conversion, pre-scan cycle and conditioning of the phase detector.

ii) Fourier analysis of the scan cycle, and

iii) Final averaging and corrections

Sections i) and iii) are performed by two separate microprocessors, while section ii) (the Fourier analysis) is carried out by dedicated fast-acting hardware. A block diagram of the bearing processor sub-system is shown in Fig. 5-1.

5.2 Computation of the Bearing Angle

The computation of the bearing is based on the Fourier analysis of the phase waveform, the bearing being given by the phase of the fundamental scan frequency. To achieve this, the waveform is first sampled and then converted to numerical values. As the antenna is made of 16 dipoles, then 16 different samples are produced per rotation.

The samples are then multiplied by the sine and also by the cosine value of the angle corresponding to the dipole selected. The north dipole is at 0° and the East one is at 90° and so on. Each result is added to the previous one, and so on for a complete cycle. If each sample is denoted by X_i (i being the dipole number ranging from 0 (North reference) to 15), then after one cycle the following two results are available.

$$\left(\sum_{i=0}^{15} X_i \cos (22.5^{*} i) \right) \quad \text{and} \quad \left(\sum_{i=0}^{15} X_i \sin (22.5^{*} i) \right)$$

(360/16 = 22.5)

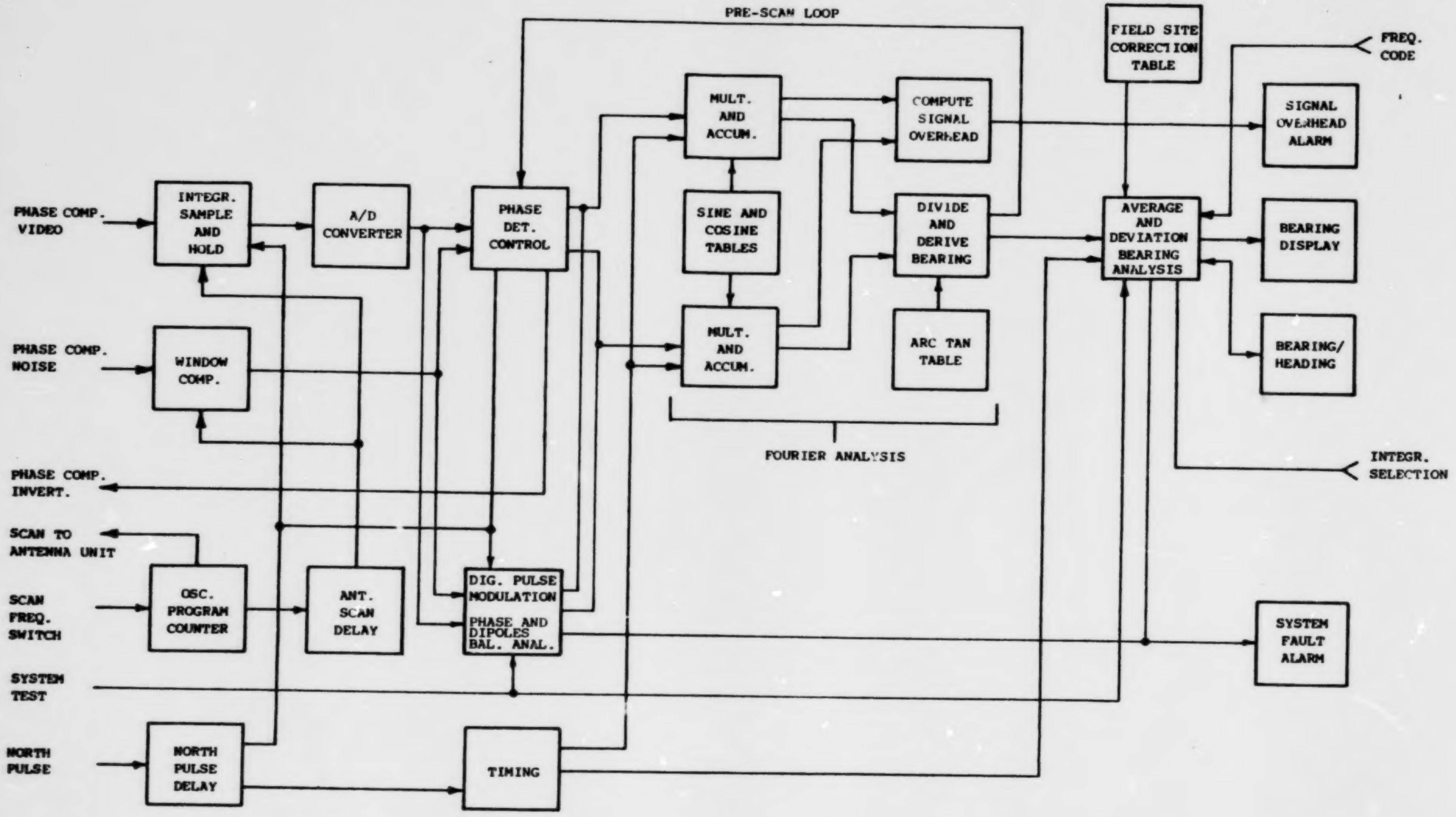

PRE-SCAN LOOP
PHASE COMP. VIDEO
PHASE COMP. NOISE
PHASE COMP. INVERT.
SCAN TO ANTENNA UNIT
SCAN FREQ. SWITCH
SYSTEM TEST
NORTH PULSE
INTEGR. SAMPLE AND HOLD
WINDOW COMP.
OSC. PROGRAM COUNTER
NORTH PULSE DELAY
A/D CONVERTER
ANT. SCAN DELAY
PHASE DET. CONTROL
DIG. PULSE MODULATION
PHASE AND DIPOLES BAL. ANAL.
TIMING
MULT. AND ACCUM.
SINE AND COSINE TABLES
MULT. AND ACCUM.
COMPUTE SIGNAL OVERHEAD
DIVIDE AND DERIVE BEARING
ARC TAN TABLE
FOURIER ANALYSIS
FIELD SITE CORRECTION TABLE
AVERAGE AND DEVIATION BEARING ANALYSIS
FREQ. CODE
SIGNAL OVERHEAD ALARM
BEARING DISPLAY
BEARING/ HEADING
INTEGR. SELECTION
SYSTEM FAULT ALARM

FIG. 5-1

BEARING PROCESSOR BLOCK DIAGRAM

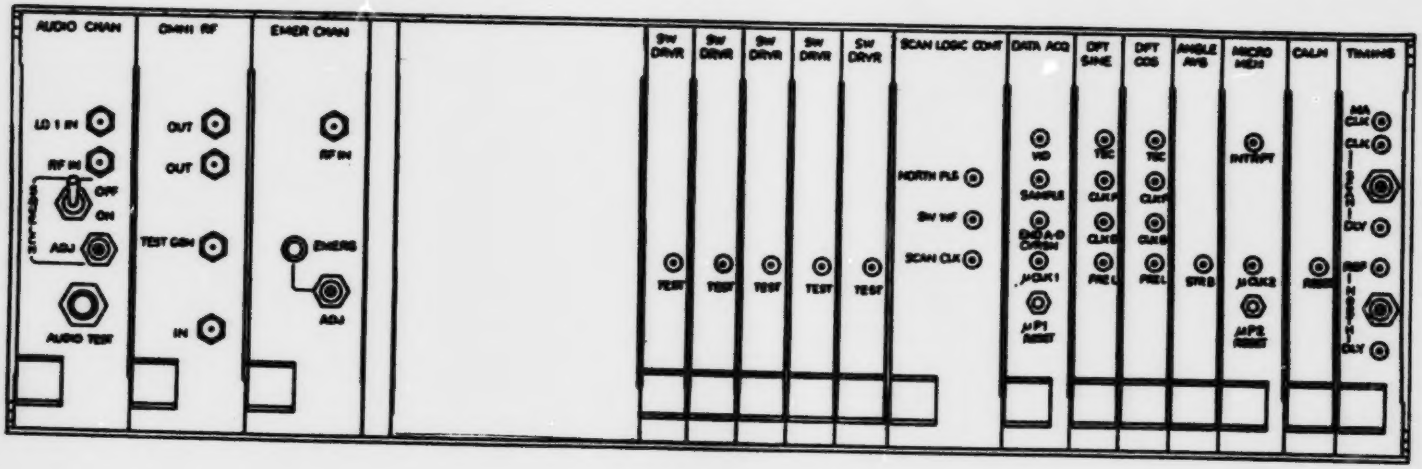

AUDIO CHAN
LO 1 IN
RF IN
OFF
ON
ADJ
AUDIO TEST
OMNI RF
OUT
OUT
TEST GEN
IN
EMER CHAN
RF IN
EMERG
ADJ
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SW DRVR
TEST
SCAN LOGIC CONT
NORTH PLS
SW INF
SCAN CLK
DATA ACQ
VID
SAMPLE
END A-D CNVSN
μCLK 1
μP1 RESET
DFT SINE
TEC
CLK F
CLK B
PREL
DFT COS
TEC
CLK F
CLK B
PREL
ANGLE AVG
STRB
MICRO MEM
INTRPT
μCLK 2
μP2 RESET
CALM
RESET
TIMING
MA CLK
CLK
DLY
REF
DLY

FIGURE 5-1-1

DF PROCESSOR

The sum of the sine products are then divided by the sum of cosine products. The arctangent of the result will give the bearing.

$$\text{Bearing} = \text{arctg} \left(\frac{\sum_{i=0}^{15} X_i \sin(22.5^* i)}{\sum_{i=0}^{15} X_i \cos(22.5^* i)} \right)$$

The Data Acquisition board is used to sample the phase waveform and to convert those samples to numerical values. These values are then sent to a DFT (Digital Fourier Transform) card which computes the sum of sine, and, at the same time, to another DFT card for the sum of cosine computation. The two results are finally read by the microprocessor which computes the bearing angle for each scan cycle.

5.3 Integration of Noise

Direction finding by cyclical modulation of phase is easily accomplished when the signal is relatively strong. However, as the signal strength decreases, the bearing readout begins to fluctuate as a result of effective differential modulation of phase, caused by the background noise - internal or external to the system. If one assumes that the noise is random, then the fluctuation can be reduced by successive integration over a period of time. The bearing accuracy becomes then a trade-off between sensitivity and the response time.

The function of integration or averaging is performed successively in four different stages:

(1) 16 Dipole pairs are scanned around the array circle, giving 16 samples of phase difference for the Fourier analysis to determine the bearing angle.

(2) The pulse-width modulated signal derived from the phase detector is first integrated and then filtered to produce a phase waveform of scan frequency showing the steps of dipole pair switching.

(3) A sampling window of accurately fixed time width is applied over the flat section of each step. Over this time, a linear integrating circuit collects a charge proportional to the sample size, while averaging any ripple caused by noise or modulation of signal. The charge is held at the end of the window period and handed over for A/D conversion and the Fourier analysis.

(4) The Bayly Quasi-Doppler DF System has provision for four integration time constants, selected automatically, giving response times from 0.1 seconds to 0.8 seconds, the longest one being used for the weakest signal levels. Each scan cycle is analyzed and the obtained bearing angles are further averaged over a given number of scan cycles: 8 for a 0.1 second response, up to 64 for a response of 0.8 seconds.

5.4 Pre-scan Cycle and the Correction to Phase Detector

The phase detector and its follow-up integration filter circuit present a periodic waveform of phase output made up of 16 steps for each scan cycle. Owing to certain internal reflections of the array, contribution of noise and receiver unbalance, it is possible for the peak steps of the phase waveform to reach, or even exceed, the ±180° limits which determine the normal range of operation of the phase detector. Under these circumstances, the phase waveform indicates isolated step readings of reverse polarity, leading to an error in the computed bearing.

Knowing which phase steps are exceeding the detector range, and what is their polarity, it is still possible to obtain the correct measurement by shifting the phase detector characteristic by 180° (by inverting one of the input channels), and then correcting digitally for the amount of the shift. To make this possible, it is necessary to run a complete scan cycle (pre-scan) at the start of the processing sequence, and to analyze the phase steps for close approach to the limits. This is done by the first microprocessor on the data acquisition board. The pre-scan cycle is run through with the normal polarity of the phase detector and a bearing angle is computed from the results. Owing to possible step reversals, it is recognized that this bearing angle may be in error by as much as ±10o, so the reading is not presented on the display. However, this accuracy is sufficient to carry out a correction procedure for a number of consecutive scans. For this purpose, any step positions are noted which exceed the ±130° limit. In these positions, the detector channels are reversed for the follow-up scans so that their phase readings can be taken nearer the centre of the detector characteristic. These step positions are counted from a nominal zero position determined by the bearing readout of the pre-scan cycle. The corrected steps which appear in the first eight positions of the scan cycle (positive half cycle) are then moved back by -180° in the digital section of the processor. Corrected steps in the second eight positions (negative half cycle) are then moved by +180°.

The final result of this process is a virtual extension of the phase characteristic of the phase detector to ±230°. The pre-scan required for detector corrections is repeated every nine cycles, i.e. each pre-scan cycle is followed up by eight corrected scans which are used for averaging and display of the corrected bearing.

A further detection network is employed to take care of errors in the close vicinity of the 180° discontinuity, where the phase detector is prone to fluctuate between positive and negative values.

This unstable condition is detected by tapping the phase comparator output and integrating it with a sufficiently small time constant to retain the ±180° noise at its full amplitude. This noise is then amplified and applied to a comparator to cause inversion of the phase detector input, and thus cut out the noise.

5.5 Signal Overhead Computation

The Doppler DF principle lends itself to determination of the angle of elevation, as well as that of the bearing of the target transmitter. Whereas the bearing is given as the phase angle of the phase waveform relative to the North position, the elevation is a function of the relative amplitude of the phase waveform.

Thus, if the instantaneous value of the phase waveform is e

$$e = E \cos \varepsilon \sin (\omega t + \varphi)$$

Where:
- E is the maximum amplitude of the waveform
- ε is the angle of elevation of the target above ground
- ω is the 2π x scan frequency
- and φ is the bearing angle relative to North

The Fourier analysis computes the sum components A and B of the sine and cosine of the bearing angle, where:

$$A = \sum_{i=0}^{i=15} X_i \cos (22.5\, i) \quad \text{and} \quad B = \sum_{i=0}^{i=15} X_i \sin (22.5\, i)$$

The amplitude of the fundamental scan frequency can be calculated as:

$$E \cos \varepsilon = \sqrt{A^2 + B^2}$$

Hence, the elevation angle $\varepsilon = \arc\cos \sqrt{\frac{A^2 + B^2}{E^2}}$

E is maintained constant by a set of amplitude limiters and it corresponds to the scan frequency amplitude of the phase waveform when the target is at ground level.

The 'signal overhead' alarm is activated when $\sqrt{\frac{A^2 + B^2}{E^2}} \leq \cos 60° \leq 0.5$

or (in practice) $\frac{A^2 + B^2}{E^2} \leq 0.25$

5.6 Bearing/Heading Conversion

Both bearing displays, digital as well as analog, show the bearing angle of the target as seen from the DF site. By pressing the 'Heading' button, the operator has a choice of indicating the heading direction which has to be followed by the pilot in order to reach the airport. On this command, both the digital and the analog indicators change to Heading and a green light comes on to indicate the condition. The conversion from bearing to heading is by a shift of 180° and is obtained digitally as part of the program of the second microprocessor (Microprocessor and Memory Module).

5.7 Determination of Data Valid Condition

The Fourier analysis and microprocessor system used for processing the bearings has effectively a wide band characteristic, and will respond to any sequence of samples from the phase detector output. Thus, when there is no signal present, the bearings computed in a sequence of scan cycles will show a wide and random fluctuation. This would obviously be confusing for the operator who does not wish to be distracted when there is no plane to follow.

To avoid this inconvenience, a 'data valid' concept is established and the readings which do not meet the data valid criterion are simply blanked out.

A bearing readout is obtained by averaging a number of individual scan bearings 8 to 64 according to the automatic setting of the integration constant. In addition to the average value of bearing, a second quantity is computed equal to a maximum deviation spread. If this spread exceeds an agreed limit, the obtained average data is declared invalid and the displays are blanked out. For the 16 dipole installation, it was found that a spread limit of 10 degrees will reduce the noise fluctuation of bearing to approximately 1° or better at the 5 uV/m sensitivity limit.

5.8 Site Error Correction

Any DF system is subject to bearing errors depending on azimuth and frequency and on the complex status of environmental conditions. The bearing errors are a combination of:

i) Instrumental errors (internal to the system)

ii) DF field site errors

iii) Transmitter site errors

The instrumental errors are a fixed part of the system and quite repeatable. They are limited by a tight set of specifications.

The DF field errors consist of the effect of diffraction and reflections from objects in the close proximity to the DF site (up to 20 wavelengths away). They can be calibrated to some approximation for a fixed configuration of conducting objects (wires, vehicles, ladders, antenna whips, etc.). They may also be affected by weather and the condition of the ground.

Transmitter site errors may be caused by reflecting objects in the vicinity of the transmitter or by directivity of the transmitter antenna. This type of error usually appears in ground transmissions, such as from the control tower, or from a portable transmitter used for calibration. This error is often frequency dependent.

The digital bearing processor of the Bayly prototype can be programmed to compensate for a large proportion of the bearing errors so as to present the operator with a more accurate bearing capability. The compensation is incorporated in the software of the second microprocessor (Microprocessor and Memory Module) and takes care of the combined area of azimuth and frequency, in steps of 11.25 degrees, and for up to 5 frequency sub-bands.

The compensation effectively reduces the combination of errors i) and ii) (instrumental and DF field site). The setting up procedure requires a set of calibration charts for the frequencies and azimuth points in question. Bearing errors are then computed from these charts and a set of corrections is programmed into the microprocessor memory.

5.9 Bearing Processor Specifications

5.9.1 Functional

(a) Principle : Digital data processing for computing bearing and elevation of an incoming signal based on 16 samples per scan of antenna rotation.

(b) Scan Frequency : 100 Hz approx. ±10%

(c) Response Time : 0.1 sec. plus Integration Constant (1, 2, 4 or 8 multiplied by 0.125 sec.)

(d) Accuracy : 0.2°

(e) Readout Resolution : 0.1°

(f) Sample Window : Integration, sample and hold of the steady state level of each input pulse

(g) Integration of Noise : Rejection of excessive error compared against a running average of eight.

Integration of average result of 8, 16, 32 or 64 samples, according to setting of the integration constant.

(h) Control of Phase Detection Range : To enable acceptance of phase angle samples up to ±230°.

(i) Automatic Reset : To restart the programs when power is applied to the system, or after an emergency stop of the system.

(j) Inputs:

North Pulse (0° bearing reference) : 200 mV p-p, 10 us approx.

Phase Step Video : Normal Level ±5.8V, ±0.1V

Phase Detector Noise : The level is 5% higher than the phase step video

Frequency Code : 8 MSB bits binary code TTL Level

Integration Constant : 2 bits binary code TTL Level

QDR/QDM : TTL Level

(k) Outputs:

Scan Clock : 32 times scan frequency, 100 mVolt p-p

Bearing/Handling Display : 4 digits BCD format TTL Level

Data Ready : TTL Level

Data Valid : TTL Level

Signal Overhead : Set to activate when target elevation ≥60° TTL level

(l) North Pulse Delay Adjustment : To compensate for group delay of the DF system (20-220 us)

(m) Scan Delay Adjustment : To allow correct setting of the sample window

(n9 Phase Detection Noise Adjustment : To adjust detection limits of the ±180° threshold noise

5.9.2 Electrical Power

+5V, ±5%

±15V, ±1V

6.0 DISPLAYS AND CONTROLS SUB-SYSTEM

6.1 Control and Display Functions

All control and display functions for the Doppler DF are handled by control/display panels. There are normally two - one at the receiver site (also called the 'Remote Panel') and one at the Operator's site (also called the 'Local Panel'), although a system may use more than one Operator's Control Panel. The displays and controls are almost identical on both panels, with the exception of the circular display, the storage display and its controls (provided on the Operator's Panel only) and the LOCAL/REMOTE switch (Receiver Control Panel) -vs- the MASTER/SLAVE switch (Operator's Control Panel). Communication between the two control/display panels is over a standard 4-wire telephone line which carries the data (FSK) and voice (receiver audio or optional telephone conversation between the two sites).

The requirements for the control and display sections are outlined below:

6.2 Requirements for Remote (Receive) Site

(a) The following data is generated by this section:

Bearing/Heading, 4 digits, BCD format

Channel Number, 1 digit, BCD format
Frequency, 6 digits, BCD format

Emergency Alarm : When a signal is received on the Emergency Channel

Sense Indication : Bearing (QDR) or heading (QDM)

Data Valid : To indicate that the displayed bearing is meaningful

Signal Overhead : Indicates that the transmitting craft passes over the site (elevation $\geq 60^\circ$)

Remote/Local Indicator : Tells the operator if the receiver is under the control of the Control Centre or is operated by a person at the Receiver Site

System Alarm : To detect and report a break in communication with the Control Site on a System Fault

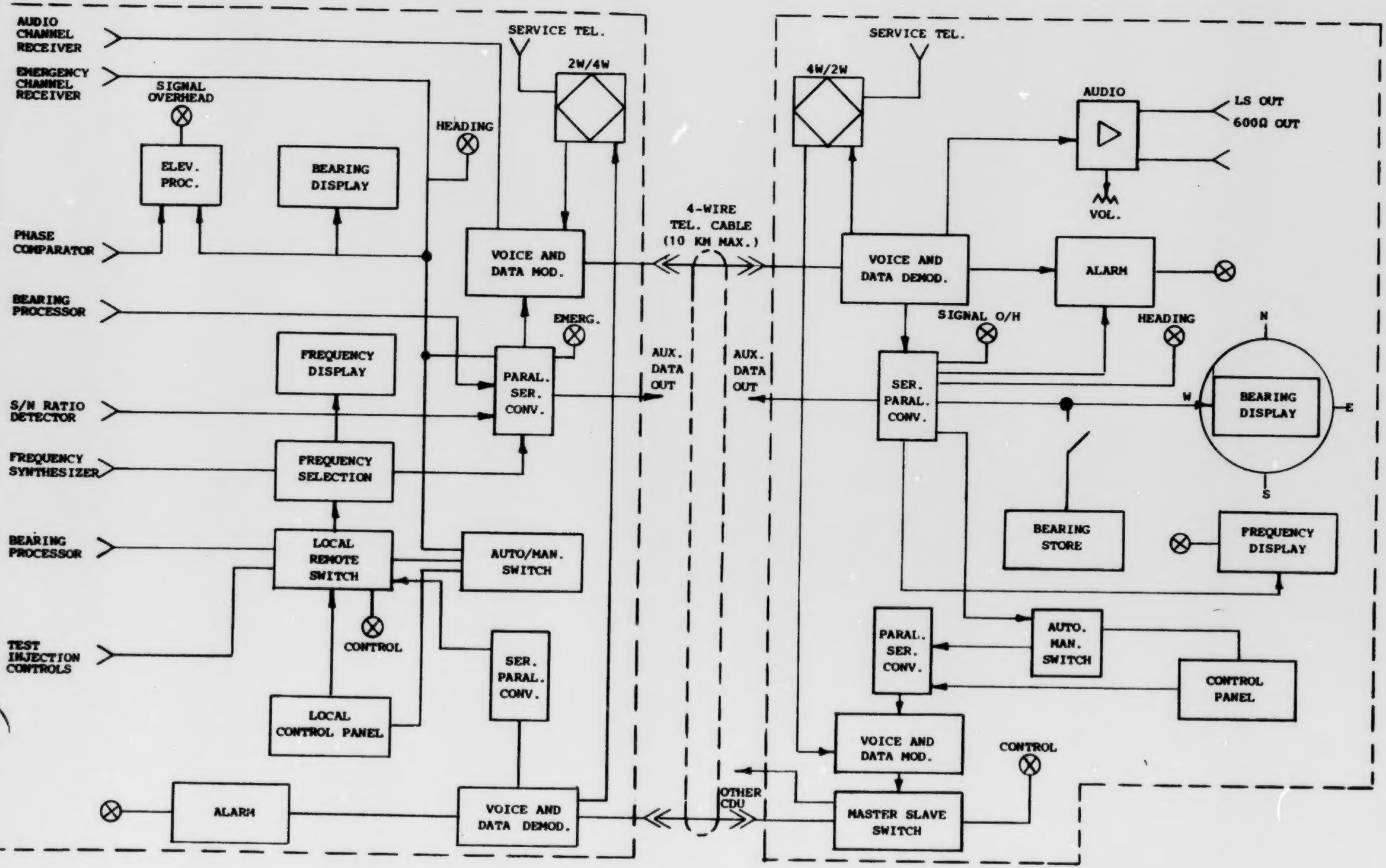

AUDIO CHANNEL RECEIVER
EMERGENCY CHANNEL RECEIVER
SIGNAL OVERHEAD
ELEV. PROC.
BEARING DISPLAY
HEADING
SERVICE TEL.
2W/4W
PHASE COMPARATOR
VOICE AND DATA MOD.
BEARING PROCESSOR
EMERG.
FREQUENCY DISPLAY
PARAL. SER. CONV.
S/N RATIO DETECTOR
FREQUENCY SYNTHESIZER
FREQUENCY SELECTION
BEARING PROCESSOR
LOCAL REMOTE SWITCH
AUTO/MAN. SWITCH
TEST INJECTION CONTROLS
CONTROL
SER. PARAL. CONV.
LOCAL CONTROL PANEL
ALARM
VOICE AND DATA DEMOD.
4-WIRE TEL. CABLE (10 KM MAX.)
AUX. DATA OUT
AUX. DATA OUT
OTHER CDU
SERVICE TEL.
4W/2W
AUDIO
LS OUT
600Ω OUT
VOL.
VOICE AND DATA DEMOD.
ALARM
SIGNAL O/H
HEADING
N
W
E
S
BEARING DISPLAY
SER. PARAL. CONV.
BEARING STORE
FREQUENCY DISPLAY
PARAL. SER. CONV.
AUTO. MAN. SWITCH
CONTROL PANEL
VOICE AND DATA MOD.
CONTROL
MASTER SLAVE SWITCH

FIG. 6-1

OPERATOR AND RECEIVER CONTROL/DISPLAY SIMPLIFIED BLOCK DIAGRAM

(b) The following data is either received from the Operator Control site or generated from the receiver control panel and must be processed at the Receiver site.

Desired channel number (10 preset channels and Emergency) or operating frequency.

Sense selection : Bearing (QDR) or heading (QDM)

Integration Constant Selection (automatic control 4 positions)

Auto/Manual Selection of the Emergency Channel

Remote Power ON/OFF : To permit Receiver shutdown and activation from the Control site

System Test Facility : Can select one of 3 different scan frequencies to minimize interference

(c) Another control feature of the Receiver site:

Remote/Local Control Switch : To transfer control from the Control site to the Receiver site

6.3 Requirements for Local (Operator's) Site

(a) The signals described in section 1.6.2 (a) are processed to provide the following indications:

4 Digit Bearing/Heading Readout (the 4th digit can be disabled)

Sense Indicator Lamp to alert the operator that the heading is displayed.

Channel number indicator (10 channels + Emergency) and/or Receiver frequency readout

System Alarm Warning Lamp

Emergency Channel Selection Indicator

Data Valid Indication

'Signal Overhead' Indicator Lamp

(b) To generate the signals described in section 6.2 (b), the following controls are provided:

System Test Selectors : Selection of 3 different tests

Antenna Scan Frequency : Selection of 3 different frequencies

Auto/Manual Emergency Selector

Heading/Bearing Selector (default to 'Bearing' mode)

Remote Receiver Power ON/OFF

Preset Channel Selection : 10 presettable and 1 Emergency Channel

OR

Frequency Selection : Any one of the 720 channels used in the VHF ATC band

(c) Other features at the Control Site:

Analog Bearing Display : A circle of 72 LED indicators on an adjustable compass rose (5° steps)

Storage of Bearing or Headings on demand

Aux Data Output : Parallel Format with Connector

Voice Output over an external speaker as well as an Auxiliary output

6.4 Operator's Control and Display Panel

The system is normally controlled from one Operator's Control/Display Panel, which would be located in the airport's control room, while the Receiver Control/Display Panel would be used for maintenance purposes only. Additional Operator's Control/Display Panels may be added to the system to extend the monitoring and control capabilities to other locations.

Fig. 6-2 shows the front panel of the Operator's Control/Display Panel, while Table 1.6 provides a detailed description of the controls and displays. As mentioned previously, the controls and displays on the Receiver Control/Display Panel are essentially identical.

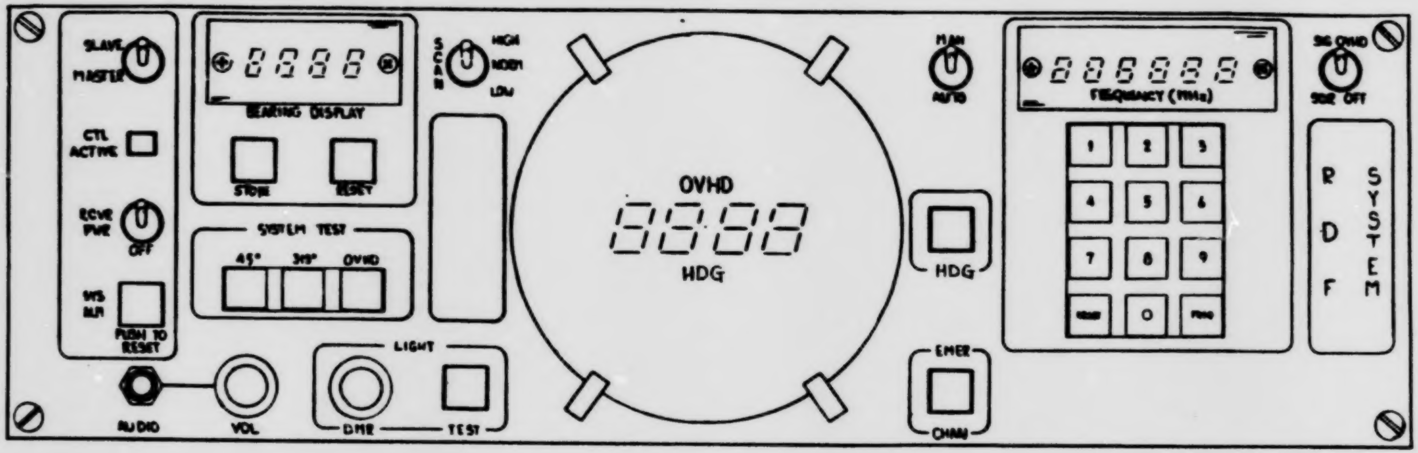

SLAVE
MASTER
CTL ACTIVE
RCVE PWR
OFF
SYS FLT
PUSH TO RESET
AUDIO
VOL
BEARING DISPLAY
STORE
RESET
SYSTEM TEST
45°
315°
OVHD
LIGHT
DMR
TEST
SCAN
HIGH
NORM
LOW
OVHD
HDG
MAN
AUTO
HDG
EMER
CHAN
FREQUENCY (MHz)
1
2
3
4
5
6
7
8
9
0
SIG CMND
SDR OFF
R
D
F
SYSTEM

FIG. 6-2

OPERATOR'S CONTROL/DISPLAY

TABLE 1.6
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
1.	PWR SWITCH	Applies ac power to the CDU (Control/Display Unit)	Switch will be included on production models
2.	PANEL ACTIVE lamp (white)	When lit, indicates that this CDU controls the system	See also Item 8.
3.	REMOTE POWER switch	Controls on/off power supplies in receiver and bearing processor section of the Remote Unit.	
4.	DIMMER Rotary Control	Controls brightness of panel indicator lamps and displays	Disabled for LAMP TEST
5.	LAMP TEST pushbutton	When pressed, all lamps and LED segments should light to full brightness	No DIMMER control is disabled
6.	SYSTEM ALARM lamp (red)	When flashing, indicates a malfunction of the DF System or break in the telephone cable from the CDU to the RU	Alarm latches in until reset (see Item 7 below)
7.	SYSTEM ALARM RESET pushbutton	When pressed, resets the system alarm to extinguish the SYSTEM ALARM lamp after the trouble has been cleared.	If the trouble persists, the SYSTEM ALARM RESET has no effect
8.	MASTER/SLAVE switch	When set to MASTER position, the CDU has both control and display capability. When set to SLAVE position, the CDU has display capability only.	One or several CDU's can be used in the system. Only one CDU can be MASTER at any given time (PANEL ACTIVE lamp 'on')

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
9.	PHONES jack	Used with standard headset to monitor audio (if any) on the df receiving channel using an omni-directional antenna for signal pick-up	Not a telephone facility
10.	VOLUME rotary control	Controls level of audio output from omni-directional antenna receiving channel	
11.	ANT. SCAN /1-2-3 rotary switch	Three positions for selecting the df antenna electronic rotation speed. Percentage variation is about 8% above and below mid speed (position 2)	If signal 'flicker' is present, there is one position where the effect is minimal
12.	CHANNEL or FREQUENCY SELECT pushbutton and lamp arrangement (see below)	This keyboard arrangement consists of ten illuminated pushbuttons (marked 0 through 9), a frequency mode and a frequency reset pushbutton. There are two modes of operation. See * entries below for channel select mode. See ** entries below for selectable frequency mode	
13.	0-1-2-3-4-5-6-7-8-9 pushbuttons for above keyboard arrangement with built-in indicator lamps	* Channel select mode. One pushbutton is used to select one of the ten df channels by number. The channel frequency is preset in the Receiver Unit for any channel number When a channel is selected (as above) the corresponding lamp will come 'on'.	The indicator lamps are turned on by response from the Receiver Unit to show acknowledgement of command. At the same time, the frequency to which the selected channel is preset will be displayed on the numeric LED frequency display. (see item 17)

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
14.	FREQ. MODE pushbutton (freq.) (part of the freq. selection keypad)	** Selectable frequency mode. When pressed, initiates the selectable frequency mode of the 0 through 9 pushbuttons.	The channel indicator lamp goes out when FREQ. MODE button is pressed and the last frequency that was selected in this mode is selected again. The RU is made ready to accept tuning to any frequency in the VHF ATC band, but the Receiver frequency is not changed until all 6 digits of the new frequency have been entered.
15.	FREQUENCY MHz six-place red numeral display with fixed three-place decimal resolution	The 0 through 9 pushbuttons can be used to enter a six digit frequency value on the display. When the sixth (and last) numeral is entered, the Receiver Unit is instantly retuned to the displayed df receiving frequency. The frequency entered should be a valid df channel in the VHF ATC band (Channel spacing is required to be 25 kHz	The actual switch to the new frequency can only take place when the complete channel/ frequency information has been entered.
16.	FREQ. RESET pushbutton	** Can be used during FREQ. MODE or channel select mode. When pressed, the channel lamp or the FREQUENCY MHz display (complete or incomplete) is cancelled. When cancelled, a new or corrected FREQUENCY MHz display can be entered.	The FREQ. RESET button will always leave the receiver in the channel select mode. If the frequency select mode is desired, the FREQ. MODE pushbutton must be pressed again. Note that when the amber lamp comes on, a channel has been selected.

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
17.	EMERGENCY mode MAN/AUTO mode	Selects system EMERGENCY operating mode. In the MAN position, the df system will operate normally. To operate on the emergency channel, the EMERGENCY pushbutton (see item 18) must be pressed. When the EMERGENCY light comes on, the Receiver Unit is locked on the emergency channel. The system is released from this mode when a 0 through 9 pushbutton is pressed, or when a frequency is selected.	
		In the AUTO position, a signal (call) on the emergency frequency will automatically lock the Receiver Unit on the df emergency channel. At the same time, the EMERGENCY lamp will light	If the emergency call signal fades intermittently or ceases, the system will hold in AUTO emergency mode for about 1.5 sec., then revert to the normal df channel previously selected.
18.	EMERGENCY pushbutton and indicator lamp	Used to manually select the system emergency df channel operation. The MAN/AUTO switch can be set to either position without affecting this function. When the emergency channel is selected (manually or automatically) the indicator lamp will light up by response from the receiver unit.	the EMERGENCY pushbutton is another channel select button and works the same way as the 0 through 9 pushbuttons. However, the associated frequency (121.500 MHz) is factory preset and cannot be easily altered altered in the field.

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
19.	Numerical and analog bearing display (red numerals and analog dot)	When a df bearing in a selected receiving channel has been processed, the bearing angle (in degrees) is displayed numerically across the centre of the circular clear red plastic overlay. At the same time, an analog of the bearing angle (±5°) is indicated by a red dot light at the overlay circumference.	
		The displayed bearing angle (both numerical and analog) is visible only when a valid signal is received on the selected channel (or frequency). The display will be blanked if the signal is lost, or the aircraft passes over the installation.	Normally (but see Step 20) at the instant of loss of bearing information, the numerical part of the information is automatically transferred to appear on the STORED BEARING display. This action occurs for every 'loss' so that the STORED BEARING display is always updated with the last valid display bearing.
20.	STORED BEARING numerical display	Any df bearing angle appearing numerically on the bearing display can be permanently stored on the STORED BEARING display. This is done by pressing the STORE button momentarily (no effect on the bearing display). This STORE action will also occur automatically for the first valid emergency df bearing if the EMERGENCY mode MAN/AUTO switch is in the AUTO position when the emergency signal is the last one (see item 17).	Observe that (unlike the action of Step 19), when the STORE button is used, the STORED BEARING display cannot be blanked out except by pressing the RESET button. Note also that when no valid display is shown on the bearing display, the RESET button has no immediate visible effect. However, the STORED BEARING display is unlocked and will be automatically updated when the next valid bearing is received.

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
20. (Cont'd)	STORED BEARING numerical display	The STORED BEARING/STORE feature is intended to protect the bearing information under certain operational conditions. Examples are: during aircraft overhead pass (see item 27); and during an EMERGENCY channel alert.	The Storage Mode is indicated by an illuminated 'STORE' pushbutton
		When required, the RESET button is used to 'unlock' the stored display.	The indicator lamp in the 'STORE' pushbutton is turned off.
21.	SYSTEM TEST/ 45° - 315° pushbuttons	When either pushbutton is pressed, the circular bearing display will indicate the numerical and analog angle of a test bearing corresponding to the pushbutton marking. The display is resolved from a signal radiated from the omni-directional antenna installed on the antenna array.	This feature can be used to inform the operator that the system operates correctly and to facilitate maintenance.
22.	OVERHEAD TEST	Simulates 'Signal Overhead' operation at an azimuth of 180°.	Indicates 'Signal Overhead' condition by flashing the OVHD lamp and sounding the alarm tone (see item 23.)
23.	HEADING pushbutton with indicator	When pressed, the numerical and analog bearing angle display will show a 180° change in the display angle. This shifted bearing is that of the df antenna site made from the aircraft. Ignoring wind direction vectors, it is the heading to be maintained by the aircraft if it is required to fly over the df antenna site.	
		When lit, the pushbutton lamp indicates that the numerical and analog display angle has become a heading angle.	

TABLE 1.6 (cont'd)
OPERATOR's CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

ITEM #	MARKING/NAME	OPERATING FUNCTION	REMARKS
24.	SIG. OVERHEAD indicator (LED lettering)	When lit, indicates that the aircraft is within an air space shaped like an inverted cone with its apex on the antenna site. The slope of the cone relative to ground horizontal is about 60°.	The bearing display will be blanked during this condition since any reading would be too inaccurate to be useful. However, as usual, when the bearing display becomes inactive, the last valid reading will be transferred to the 'Stored Display'.

6.5 Receiver Control/Display Panel

On the Receiver Control/Display Panel, Item #8 (MASTER/SLAVE) is called the LOCAL/REMOTE switch. The function is very similar: In the REMOTE position, the Receiver Panel has control and display capability, while any Operator's Panels will have monitoring function only (their PANEL ACTIVE lamps will be off no matter where the MASTER/SLAVE switch is set, to show that they are no longer in control). In the LOCAL position, control is transferred to the Operator's Panel(s) and the Receiver Control/Display Panel is acting only as a monitor.

Item #20 (STORE) and the analog bearing display referred to in item 19 are not incorporated in the Receiver Control/Display Panel, and any reference to the 'Stored Display' or the analog bearing display should be deleted for this unit. Physically, the digital (or numerical) Bearing Display is moved to the location held by the STORED DISPLAY on the Operator's Panel.

The layout of the Receiver Control/Display Panel is shown in Fig. 6-3.

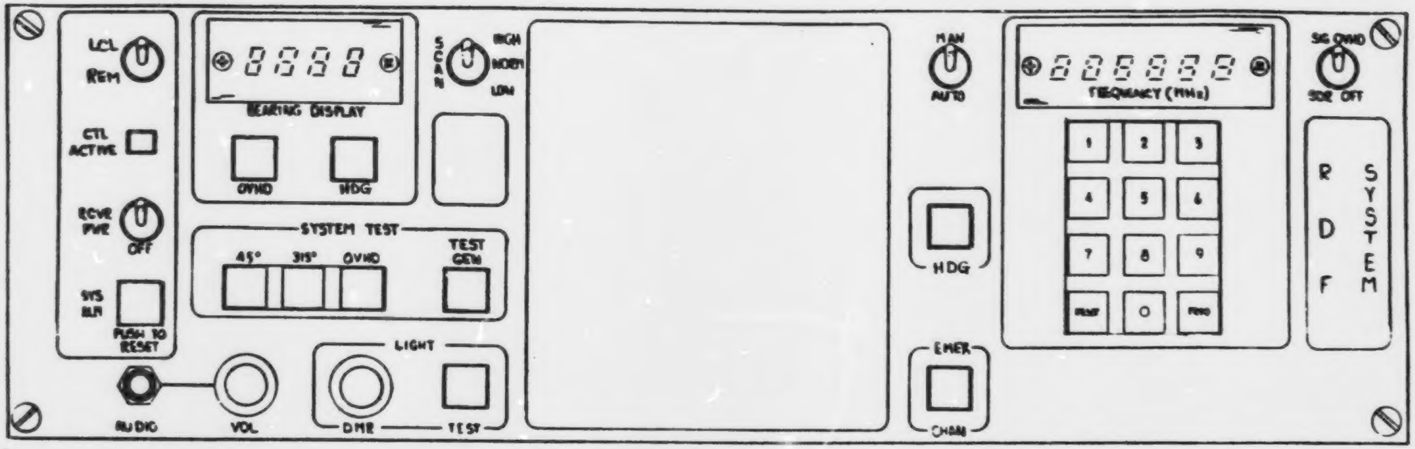

LCL
REM
CTL ACTIVE
RCVR PWR
OFF
SYS BLT
PUSH TO RESET
AUDIO
VOL
BEARING DISPLAY
OVHD
HDG
SCAN
HIGH
NORM
LOW
SYSTEM TEST
45°
315°
OVHD
TEST GEN
LIGHT
DMR
TEST
MAN
AUTO
HDG
EMER
CHAN
FREQUENCY (MHz)
1
2
3
4
5
6
7
8
9
0
SIG OVHD
SDR OFF
RDF
SYSTEM

FIG. 6-3

RECEIVER CONTROL/DISPLAY

7.0 DATA AND VOICE TRANSMISSION SUB-SYSTEM

7.1 General Description

The VHF Doppler DF system can be operated either from the Operator's Site ('Local' Control/Display Panel) or from the Receiver Site ('Remote' Control/Display Panel). Communication between the two panels is over a standard 4-wire telephone line which carries the data (FSK transmission) and the voice (receiver audio or optional telephone conversation between the two sites).

The following features are incorporated:

Link operates on a standard 4-wire telephone quad.

'Data over Voice' operation with voice frequencies limited to 2.3 kHz; Data channel to use FSK in the 2.5 to 3.0 kHz band.

Data generated at either site is serialized and sent as a 32 bit package in a 0.1 sec. time frame.

Data received at either site is re-converted to parallel form for further processing.

Voice will normally come from the received transmission, but can be replaced by a telephone link if personal communication is needed between the two sites.

Transmission levels of voice and data can be adjusted in both directions by up to 40 dB to allow for losses in the telephone line. A block diagram of the overall data and voice sub-system is shown in Fig. 7-1.

7.2 Data Transmission

Data communications between the local and remote sites is accomplished using frequency shift keying (FSK) modulation within the 3 kHz limitation of a standard telephone line, and by limiting the voice band to 2.3 kHz so that the data signals can be placed above the voice band on the line. One line is dedicated to each direction, so that the format and frequencies used in each direction can be identical.

All data to be transmitted should be in Binary or BCD format. A 32 stage Parallel-In/Serial-Out shift register converts the data to serial format and sends it to the FSK Modulator. The clock rate for the register is 416.67 Hz. This, and other critical frequencies, are derived from a 1.76 MHz crystal controlled master clock.

The data transmission is initiated by a start pulse which comes once every 100 msec. Thus, the format of transmission is: 1 Start Bit + 30 Data Bits + 1 Stop Bit, or a total of 32 Bits sent within 80 msec., followed by a 20 msec. pause (to allow time for processing).

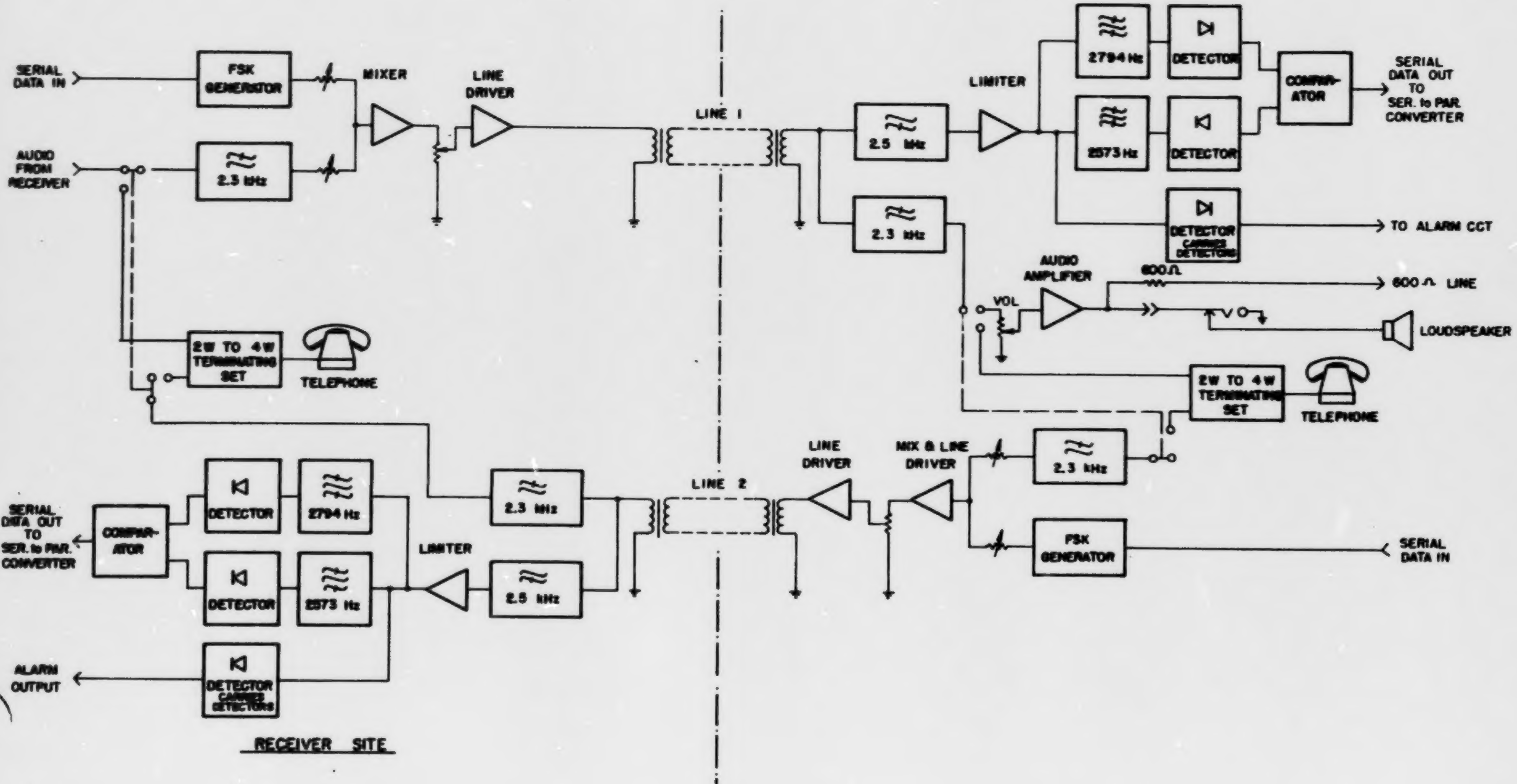

SERIAL DATA IN
AUDIO FROM RECEIVER
FSK GENERATOR
2.3 kHz
MIXER
LINE DRIVER
LINE 1
2W TO 4W TERMINATING SET
TELEPHONE
2.5 kHz
2.3 kHz
LIMITER
2794 Hz
2573 Hz
DETECTOR
DETECTOR
COMPAR-ATOR
SERIAL DATA OUT TO SER. to PAR. CONVERTER
DETECTOR CARRIER DETECTORS
TO ALARM CCT
AUDIO AMPLIFIER
VOL
600Ω
600 Ω LINE
LOUDSPEAKER
2W TO 4W TERMINATING SET
TELEPHONE
SERIAL DATA OUT TO SER. to PAR. CONVERTER
COMPAR-ATOR
DETECTOR
DETECTOR
2794 Hz
2573 Hz
LIMITER
2.3 kHz
2.5 kHz
LINE 2
LINE DRIVER
MIX & LINE DRIVER
2.3 kHz
FSK GENERATOR
SERIAL DATA IN
ALARM OUTPUT
DETECTOR CARRIER DETECTORS
RECEIVER SITE

FIG. 7-1

DATA/VOICE TRANSMISSION BLOCK DIAGRAM

The FSK Modulator synthesizes a sine wave of 2573 Hz (Bit = 0) or 2794 Hz (Bit = 1) from the master clock. The synthesizer creates the sine wave in 18 steps, so that the clock frequency has to be 18 times the output frequency. This clock frequency is derived by dividing the master clock either by 38, or by 35, depending on whether the transmitted bit is a 0 or a 1. When no data is transmitted (e.g. during the 20 msec. pause), the synthesizer generates a steady signal of 2573 Hz.

Audio signals may be either from the received radio signals, or the optional telephone facility. These signals are passed through a 2.3 kHz low pass filter to eliminate unwanted harmonics which may interfere with the data band and the audio and data tones are combined in a mixer. A buffer amplifier provides the proper power levels and source impedance for the telephone line.

7.3 Data Recovery

At the receiving end of the link, the audio and data signals are separated again by low and high pass filters.

A carrier detector monitors the data tones to activate the System Alarm if these tones should be interrupted. The FSK Demodulator recovers the data in serial form and sends them on to the Serial-to-Parallel Converter. The Serial-to-Parallel Converter consists of a 32 stage Serial-In/Parallel-Out shift register whose clock is triggered by the reception of the Start Bit. Again, this clock is derived from the local master clock to guarantee its accuracy and stability.

When the Start Bit appears on stage 32, the circuit checks for the presence of the Stop Bit in stage 1 and then stops the register clock. Various strobes are now generated to initiate the appropriate processing and, finally, the register clock circuitry is reset to wait for the next Start Bit. If the Stop Bit is not found, the transmission is assumed to be in error, the data is cleared from the shift register, and no processing is initiated. Thus, checking for both the Start and the Stop Bits provides a simple form of error detection to check the data stream for proper format. For most of the functions controlled by the data stream, this feature provides sufficient security since the information is updated every 1/10 of a second and an error in a display would be corrected in the next update causing, at worst, a slight flicker in the display.

Almost all the critical functions are at the Receiver Panel and since there is a considerable number of spare bits in the 'Operator-to-Receiver' direction, it is possible to use two bits (at different positions in the data stream) for each of the critical functions. The relevant bits are compared at the other end of the link and the new information will only be accepted if the status of these two bits is identical.

The above time and pulse redundancy makes it unnecessary to employ parity checks.

Functions which fall into this category are:

- Channel or Frequency Selection
- Remote Receiver Power ON/OFF
- System Test, and
- Bearing/Heading Selection

In the Receiver-to-Operator path, only the Emergency Reception needs to be secure, since it could otherwise cause an erroneous switching to the Emergency Channel.

The Bit Assignment for the data stream is as follows:

TABLE 1.7 : DATA BIT ASSIGNMENT

Bit #	Function (Operator-to-Rx)	Function (Rx-to-Operator)
1	Start	Start
2	System Test ON/OFF (1)	Digit Position Bit 2
3	System Test Position Bit 1	Digit Position Bit 1
4	System Test Position Bit 0	Digit Position Bit 0
5	Int. Const. Sel. Bit 1	Digit Value Bit 3
6	Int. Const. Sel. Bit 0	Digit Value Bit 2
7	Key Pressed (1)	Digit Value Bit 1
8	Digit Value Bit 3 (1)	Digit Value Bit 0
9	Digit Value Bit 2 (1)	Bearing Hundreds Bit 1
10	Digit Value Bit 1 (1)	Bearing Hundreds Bit 0
11	Digit Value Bit 0 (1)	Bearing Tens Bit 3
12	QDM/QDR Selector (1)	Bearing Tens Bit 2
13	Rem. Rx Pwr ON/OFF (1)	Bearing Tens Bit 1
14	Ant. Scan Freq. Bit 1	Bearing Tens Bit 0
15	Ant. Scan Freq. Bit 0	Bearing Units Bit 3
16	QDM/QDR Selector (2)	Bearing Units Bit 2
17	Digit Value Bit 0 (2)	Bearing Units Bit 1
18	Digit Value Bit 1 (2)	Bearing Units Bit 0
19	Digit Value Bit 2 (2)	Bearing Tenths Bit 3
20	Digit Value Bit 3 (2)	Bearing Tenths Bit 2
21	System Test ON/OFF (2)	Bearing Tenths Bit 1
23	Rem. Rx Pwr ON/OFF (2)	Bearing Tenths Bit 1
24	(spare)	Overhead Pass Indicator
25	(spare)	QDM/QDR Indicator
26	(spare)	Data Valid
27	(spare)	LOCAL/REMOTE Indicator
28	(spare)	System Alarm
29	(spare)	Emergency Rx (2)
30	(spare)	(spare)
31	(spare)	(spare)
32	Stop	Stop

7.4 The Voice Link

The Voice Signal from the receiver Audio Channel is passed through a 2.3 kHz low pass filter onto a mixer, where it is combined with a Data signal. The combined voice and data signal is amplified in a buffer amplifier/driver connecting to the telephone line.

At the operator's control end, the incoming signal is brought to a Voice/Data separation filter. The voice output is then amplified to drive the local loudspeaker, the volume control for which is provided on the front panel.

Two-to-four wire Hybrid modules are provided, one at each end, to facilitate connection of standard 2-wire telephones to the voice link to allow communication between the local and remote sites for maintenance purposes.

8.0 OMNI-DIRECTIONAL MONITORING RECEIVERS

8.1 Requirement

In parallel with the task of obtaining a bearing on a radio target, the DF System may be required to pick up the audio intelligence of the incoming signal mainly for its identification with that received on the communications equipment. It may also be required to constantly monitor the emergency channel frequency and to alarm the operator when an emergency signal is detected.

These two functions (basically optional) are built into the Bavly DF System with an additional facility of allowing to tune in automatically to the emergency signal and to indicate the bearing.

8.2 Configuration

The signals for the Audio and Emergency Sub-system are picked up from an omni-directional antenna situated at the centre top of the array, providing an uninterrupted reception anywhere inside the entire input band. The RF signals are amplified in the broad band amplifier module (RF Omni-Channel) in the Receiver Unit. A power divider inside this module divides the signal into two paths feeding the Emergency Receiver and the Audio Receiver respectively. Fig. 8-1 shows the block diagram of the (optional) omni-directional monitoring sub-system.

8.3 The Audio Channel

In the audio channel, the signal is tuned in by means of the same 1st local oscillator as the DF receiver, generating the 1st IF of 30 MHz. A second conversion produces the output of the second IF (455 kHz) which is filtered and fed directly to the AM detector. An audio amplifier with volume control, and an audio power stage to feed a loudspeaker, complete the circuit. A self-contained AGC circuit maintains the output constant throughout the dynamic range. An adjustable squelch circuit is provided to cut off the no-signal noise.

8.4 The Emergency Channel

The path of the emergency channel goes via a 121.5 MHz crystal filter in order to improve the adjacent channel selectivity for strong interfering signals. A crystal oscillator at 151.5 MHz provides the source of tuning in the first conversion stage. The second conversion, and the remaining circuits, are similar to the audio channel, except that the detector is d.c. type, providing a trigger output for emergency alarm or takeover, according to the position of the AUTO/MAN switch. Bandwidth of the emergency channel is adjusted for 15 kHz to accept the spectrum of an ELT signal with maximum possible frequency drift. The emergency channel monitor remains on continuously.

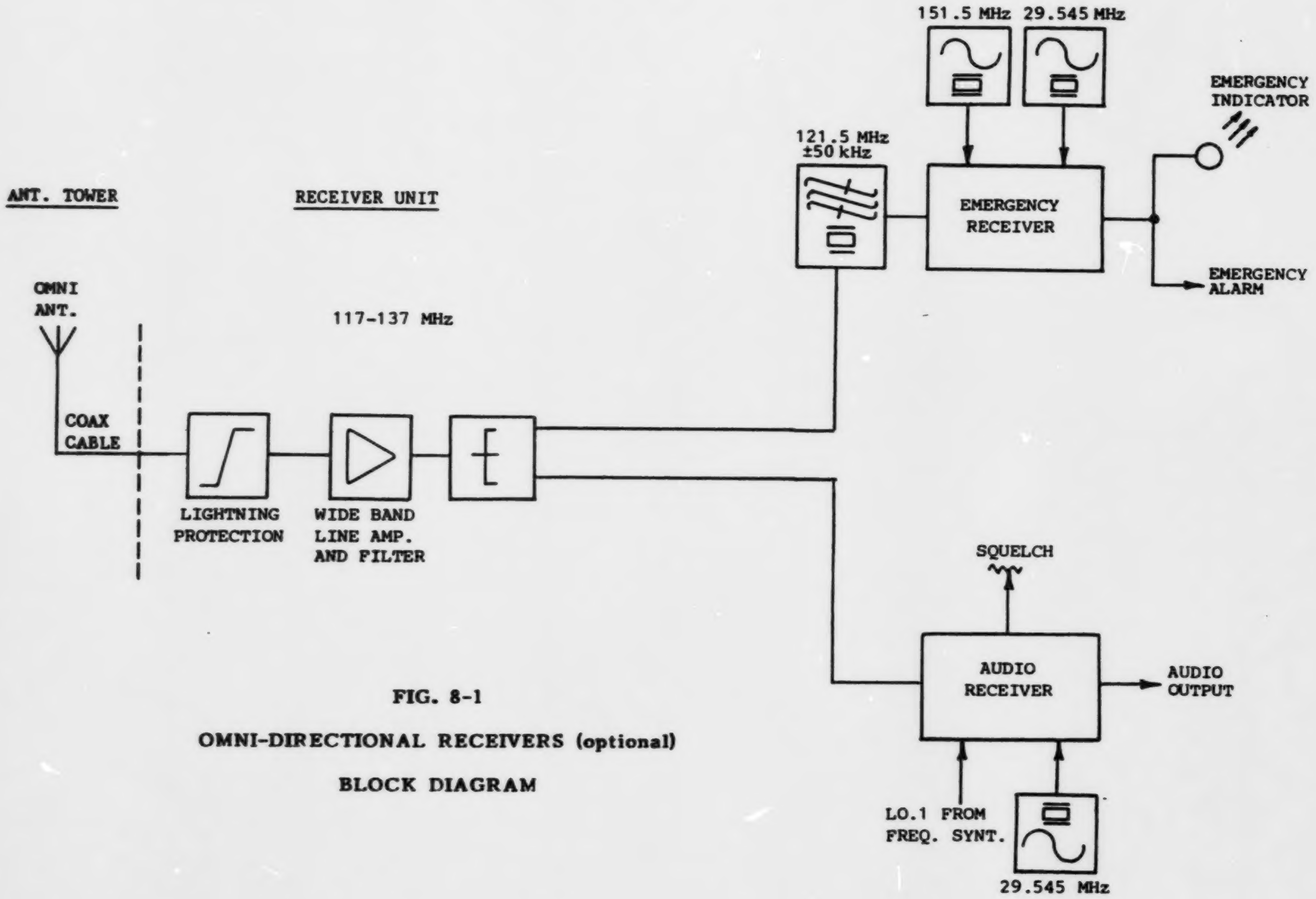

ANT. TOWER
RECEIVER UNIT
OMNI ANT.
COAX CABLE
117-137 MHz
LIGHTNING PROTECTION
WIDE BAND LINE AMP. AND FILTER
121.5 MHz ±50 kHz
151.5 MHz
29.545 MHz
EMERGENCY RECEIVER
EMERGENCY INDICATOR
EMERGENCY ALARM
SQUELCH
AUDIO RECEIVER
AUDIO OUTPUT
LO.1 FROM FREQ. SYNT.
29.545 MHz

FIG. 8-1

OMNI-DIRECTIONAL RECEIVERS (optional)

BLOCK DIAGRAM

8.5 Specification - Omni-directional Monitoring

Monitor Antenna	At centre of the DF array, omni-directional pattern
Frequency	RF input band 117.5 MHz - 136.5 MHz (can be extended to 137 MHz)
Audio Channel Tuning	Automatically tuned with the DF System
Monitoring Receiver Sensitivity (either channel)	NF 7 dB or better
Audio Detector	Amplitude Modulation (A1) up to 95%
Audio Channel Bandwidth	15 kHz at 3 dB points
Audio Output	0.5W into 8 Ohms (ext. loud-speaker) with front panel volume control)
Aux. Output	50 mW at 600 Ohms on the Operator's Control/Display Unit
Squelch Adjustment	Provided on Receiver Unit Audio Receiver Module
AGC	Provided separately on Audio Channel and Emergency Channel
Emergency Receiver Tuning	125.5 MHz activated by a separate key
Emergency Detector	Carrier presence above threshold, preset at the Receiver Unit Emergency Module
Emergency Bandwidth	15 kHz at the 3 dB points
Adjacent Channel Rejection	60 dB for interfering signals below 3 mV/m level
AUTO/MANUAL Control	At both the Receiver and Operator's Control/Display Units
Alarm	LED indicators at both the Receiver and Operator's Control/ Display Units
DF Takeover	Automatic on the appearance of an emergency signal in the AUTO position of the control

9.0 SYSTEM TEST FACILITIES

9.1 System Test

A new concept is introduced in the Bayly DF System for extended built-in testing facilities. It is based on a software program of analyzing the operation of the DF system when injected with an RF test signal from the omni-directional antenna in the centre of the array. The test frequency is the same as that to which the system is tuned, and provides accurate verification that the equipment is operational.

9.2 Test Features

1. System Test 45° : Two momentary pushbuttons are provided to give an overall check of accuracy of the entire DF system. Performed for two sample azimuth bearings, this test verifies the operation of antenna dipoles and switches, of the DF receiver and phase detector, the digital bearing processor and the associated bearing displays.
2. System Test 315°
3. Signal Overhead Test : Pushbutton facility provides a check of the signal overhead indicator and alarm.
4. Phase Balance Test : A separate pushbutton to inject the RF test signal in equal phase to all the dipole pairs provides a facility to examine dipole phase balance and the phase balance of the DF receiver channels with the aid of an external oscilloscope.

Test pushbuttons 1, 2 and 3 are for use by the operator and are available on the front panels of both the Receiver and Operator's Control/Displays. The phase balance test pushbutton is intended purely for maintenance and is located on the Receiver Control/Display only.

9.3 Principle of Operation (see Block Diagram Fig. 9-1)

An RF test signal is generated by mixing the 1st oscillator frequency with the 1st intermediate frequency (30 MHz) derived from a separate crystal oscillator. The test signal is applied via a PIN diode switch to the omni-directional antenna in the centre of the array (normally used for the monitoring audio and emergency channels). The scanning action of the Doppler DF system causes the phase detector to deliver a series of step pulses of near-zero amplitude, which can be used for a phase-balance check of the system, and for troubleshooting purposes.

9.4 Detailed Program

Press the 45° Test Pushbutton

(1) 30 MHz X-Y oscillator is switched ON. RF signal is generated in TEST GEN and applied to a switch in OMNI module.

(2) RF signal is applied to Omni Antenna (test switch in OMNI is on). The RF is picked up simultaneously in all the dipoles. Antenna scan produces a set of pulses in Phase Detector output. Each pulse is of zero amplitude since the omni pick-up is co-phasal for all the dipoles.

(3) The flat part of the pulses is sampled and integrated in the usual way across the sample window. Sample and hold outputs are applied to the A/D converter.

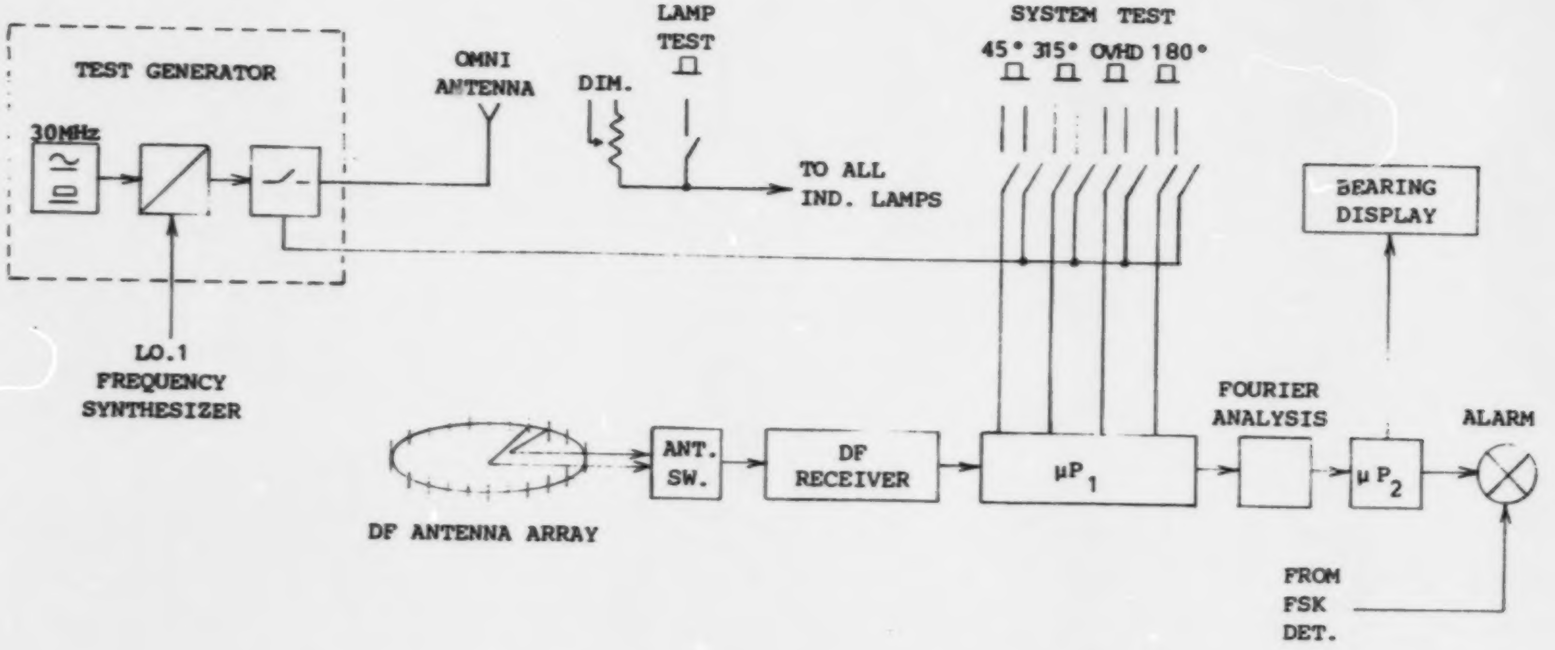
(4) Amplitudes of successive pulses are compared and checked if they do not differ by more than 30° (unequal pulses mean a defective dipole on dipole switch). If yes - give alarm, if no - proceed.

(5) Amplitudes of 16 pulses are averaged over a full scan and the d.c. offset is read out in equivalent degrees of bearing. If ≤15° - give alarm, if not - proceed.

(6) The pulse sample noise is checked by the 'window comparator' circuit. If noise present - give alarm, if not - proceed. (This test checks for any broken dipole connections).

(7) A synthetic amplitude modulation is applied to the set of pulses of a complete scan. Starting from a pulse corresponding to 45°. Amplitude of modulation is equivalent to 90°. The Fourier analysis now reads a bearing in the usual way, and indicates it on the bearing readout.

(8) The bearing readout is compared with the nominal test bearing (45°). If error is 0.5° - an alarm is given, if not - there is no action.


TEST GENERATOR
30MHz
LO.1
FREQUENCY
SYNTHESIZER
OMNI
ANTENNA
DIM.
LAMP
TEST
TO ALL
IND. LAMPS
SYSTEM TEST
45° 315° OVHD 180°
BEARING
DISPLAY
DF ANTENNA ARRAY
ANT.
SW.
DF
RECEIVER
µP1
FOURIER
ANALYSIS
µP2
ALARM
FROM
FSK
DET.

TEST BUTTONS

- System Test - 45° or 315° display computed bearing
- OVHD - pulse modulation reduced in amplitude to simulate 60° elevation
- 180° - maintenance test position for system troubleshooting (Test Generator ON)

FIG. 9-1

SELF TEST FACILITY

Press the 15° Test Pushbutton

As for the 45° except that the modulation starts at 135°.

Press Overhead Test Pushbutton

As for the 45° except for 2 conditions:

- modulation is set to 180°
- amplitude of modulation is set to <60°

Alarm Trigger

The alarm is a flashing red light which is triggered by:

(1) Any of the out-of-limit conditions reported by examination of the test pulses when pressing a System Test pushbutton.

(2) Bearing readout error <0.5° computed by the microprocessor in the final stage of the System Test.

(3) Absence of a carrier on the telephone line linking the Operator Control/Display with the Receiver Unit.

Alarms of any test operation are cancelled when the test pushbutton is released. An alarm of the carrier malfunction can be cancelled by the alarm test pushbutton.

The red alarm light flashing is accompanied by an internal beeper sound which can be turned off if not required. The beeper also sounds when there is an indication of 'signal overhead'.

9.5 Maintenance Routines

The Test Generator pushbutton gives a simulated signal source for installation check, DF system alignment, and for any maintenance checks and troubleshooting. The tests are performed with the aid of a simple two-channel oscilloscope, set to display a single cycle of the scan frequency, and triggered by the North pulse of the scanning system. The following tests are considered as regular routines:

(1) Applying Channel 1 of Scope to the output of the phase detector shows a series of sixteen flat-top pulses of equal amplitude, near the d.c. zero line. The displacement of the pulse-top average from the d.c. zero gives a measure of any phase unbalance in the DF receiver channels or in the phase detector allowing for alignment of the appropriate sections.

(2) Any 'wiggles' in the above waveform (e.g. one step up, one step down) show a defective dipole or dipole switch. The dipole number can be established by counting from the North pulse reference.

(3) Applying the 2nd channel of the Scope to the Integrator output, the relative position of the sampling window can be examined (expand the scan width as required) and adjustments can be made to the scan frequency delay and North pulse delay.

(4) Pressing one of the system test pushbuttons, instead of the phase balance test, will show test (3) above repeated with the phase modulation present. Inversions of the phase detector will show wherever the phase pulses exceed the ±130° limits.

10.0 POWER SUPPLY AND INTERCONNECTIONS

10.1 Power Distribution

The VHF Quasi-Doppler DF System is powered from a single phase AC line of 115V, 60 Hz. Separate 15A 3-pin plugs are provided for the Control/Display Units, and a separate plug is used for the main Receiver-Antenna group. The latter is provided with a remote ON/OFF switch, located on the front panel of the Operator's Control/Display Unit. In this way, both the Control/Display facilities continue operating without a break, whilst the Receiver/Processor group can be switched off when not in use (or while under maintenance).

The individual Control/Display Units have their power supplies incorporated in their rack structure in the form of detechable modules, which can be removed after the front panel is lowered.

The main Receiver/Processor power supply is assembled on a rear panel of the Receiver Unit enclosure, mounted on suitable supports to provide air flow for cooling. Its outputs are distributed to two terminal blocks: one for the Receiver Unit, and one for the Processor Unit. There is no power supply for the antenna array which contains no active elements.

All the individual power supply modules are sub-contracted items, obtained from the standard catalog of Lambda Electronics. They are all of the conventional regulator type. Switching power supplies are ruled out on account of radio interference.

10.2 Power Supplies for Control/Display Unit

The power supply modules for the Control/Display Units are housed in a separate module mounted inside each Control/Display Unit. They provide regulated outputs of +5V and ±12V DC. The +5V is derived from the +12V line via a regulator. They are constructed and wired in a manner providing a 100% safety to maintenance personnel when working on tests or troubleshooting with the front panel open.

10.3 The Power Supply Assembly of the Receiver/Processor Group

The main power assembly provides stabilized d.c. power supplies of ±24V, ±15V and +5V. These are used for the receiver, antenna switching and bearing processor modules inside the Receiver Unit. The 115V AC line is localized to the Power Supply Assembly panel, thus ensuring complete safety for any maintenance of the plug-in modules of the Receiver Unit.

10.4 **Specification**

Power Supply Assembly, Receiver/Processor

AC Input : 105-127V AC, 57-63 Hz

OUTPUT VOLTAGE	REGULATION (Line Load)	RIPPLE (RMS)	MAX. AMPS AT AMBIENT OF			
			40°C	50°C	60°	70°C
+5V	0.1%, 0.1%	1.5 mV	8.5	7.6	6.2	4.5
-24	0.1%, 0.1%	1.5 mV	2.1	1.9	1.5	1.0
+24	0.1%, 0.1%	1.5 mV	3.25	2.75	2.0	1.2
±15	0.1%, 0.1%	1.5 mV	2.0	1.6	1.2	0.8

Temperature Coefficient : 0.03% per °C

Overload Protection : Automatic Current Limit

No Overshoot (ON or OFF) : Over-voltage protection on +5V output only

Transformer Isolation : 4 KW AC input/output

EMI conducted and radiated to MIL-I-6181D

CSA certified

Ambient operating temperature range : 0° to 50°C

Storage temperature : -55°C to +85°C

10.5 **Power Supply Specifications**

Control/Display Unit

(one on each the Receiver Control/Display and Operator's Control/Display

AC Input : 105-127V AC, 57-63 Hz

OUTPUT VOLTAGE	REGULATION (Line Load)	RIPPLE (RMS)	MAX. AMPS AT AMBIENT OF	
			40°C	50°C
+12V	0.15%, 0.15%	1.5 mV	1.5A	1.35A
+5	0.15%, 0.15%	1.5 mV	100 mA	100 mA
-12	0.15%, 0.15%	1.5 mV	350 mA	300 mA

Temperature Coefficient	:	0.03% per °C
Overload Protection	:	Automatic on +12V and -12V linear
Transformer Isolation	:	2.5 KV AC input/output
Ambient Operating Temperature Range	:	0°C to 60°C
Storage Temperature	:	-55°C to +85°C

10.6 Unit Interconnections

The Doppler DF System is separated into equipment in 3 locations:

(1) The top of the mast mounted antenna array

(2) The DF site cabin installed Receiver Unit, and

(3) The Operator's Control/Display Unit in the Control Tower

Connections between the Antenna Array and the Receiver Unit are made with 17 coaxial cables. Sixteen of the coaxial cables feeding the DF receiver channels are matched in phase to an accuracy of ±1° at 130 MHz. The coaxial cables are 50 Ohms, 0.25 inch diameter, terminated with N-type connectors at each end. The remaining cable for the Omni Antenna is also coaxial and of the same type as the other 16 but has no requirement for phase matching. The Receiver Unit connects to the Operator's Control/Display by means of a standard 4-wire telephone cable. The connections are made to terminal blocks accessible from the rear of the respective cabinets.

10.7 Internal Cabling

All the coaxial connections between the Antenna and the Receiver Unit are of N type for ease of handling and reliable contacts in outdoor environment.

In the Receiver Unit, SMA connectors are adopted as standard. There are no coaxial cables in the Control/Display Unit.

The rear-wiring of all the rack shelves is done by a wire-wrapping method which has been proved reliable in the telephone industry. The exception is power supply bus bars which are intended to carry substantial currents.

An inter-connection diagram of the Receiver Antenna Siwtching and Bearing Processor modules is shown in Fig. 10-1.

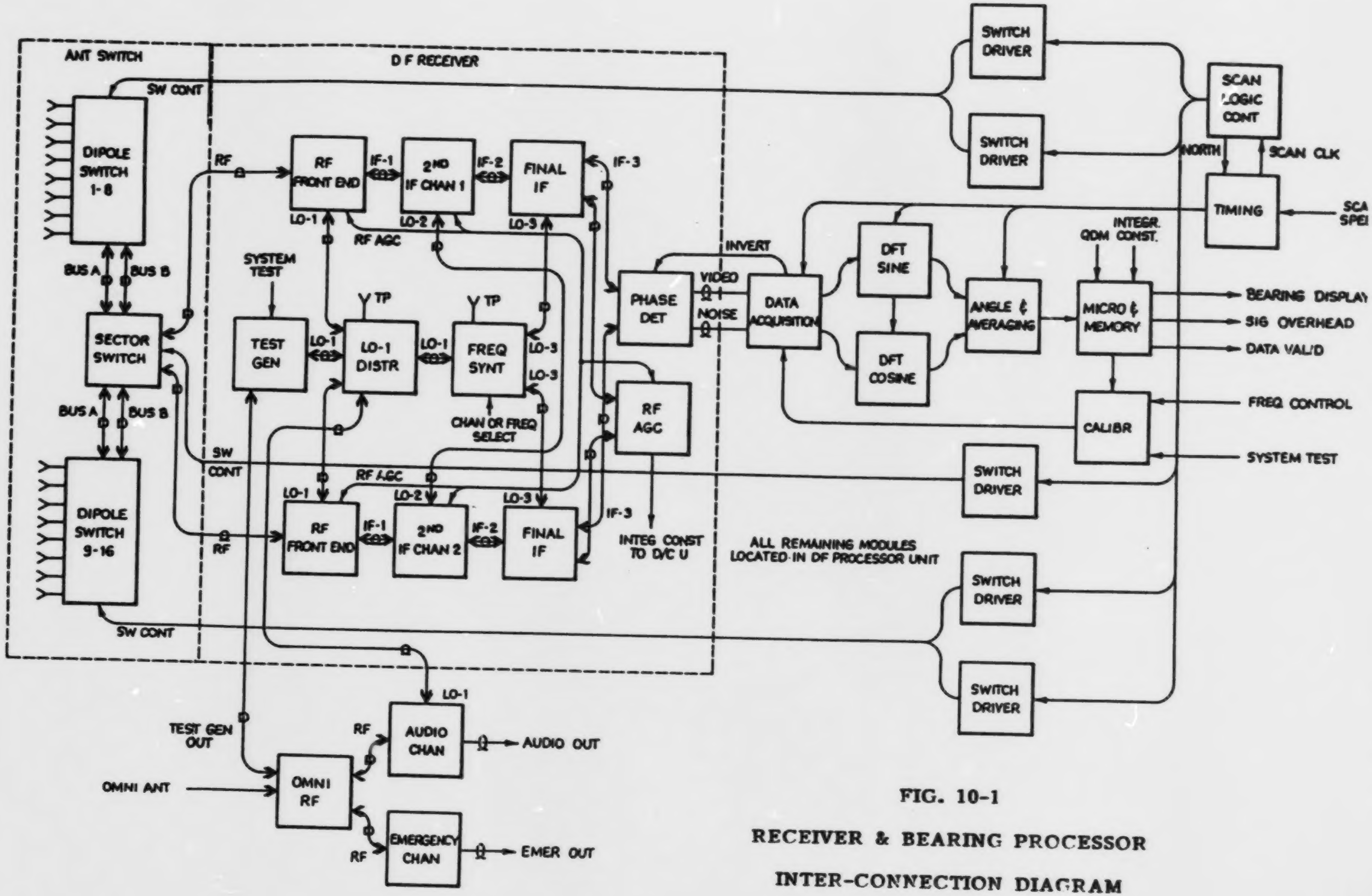

ANT SWITCH
D F RECEIVER
SW CONT
DIPOLE SWITCH 1-8
DIPOLE SWITCH 9-16
BUS A
BUS B
SECTOR SWITCH
RF
RF FRONT END
IF-1
2ND IF CHAN 1
IF-2
FINAL IF
IF-3
LO-1
LO-2
LO-3
RF AGC
SYSTEM TEST
TEST GEN
LO-1 DISTR
TP
FREQ SYNT
CHAN OR FREQ SELECT
2ND IF CHAN 2
PHASE DET
RF AGC
INTEG CONST TO D/C U
VIDEO
NOISE
INVERT
DATA ACQUISITION
DFT SINE
DFT COSINE
ANGLE & AVERAGING
QDM CONST.
INTEGR.
MICRO & MEMORY
BEARING DISPLAY
SIG OVERHEAD
DATA VALID
CALIBR
FREQ CONTROL
SYSTEM TEST
SWITCH DRIVER
SCAN LOGIC CONT
NORTH
SCAN CLK
TIMING
SCA
SPE
ALL REMAINING MODULES LOCATED IN DF PROCESSOR UNIT
TEST GEN OUT
OMNI ANT
OMNI RF
AUDIO CHAN
AUDIO OUT
EMERGENCY CHAN
EMER OUT

FIG. 10-1

RECEIVER & BEARING PROCESSOR

INTER-CONNECTION DIAGRAM

11.0 DIMENSIONAL OUTLINES

11.1 Antenna Array

The DF Antenna is a circular structure of 4.65 m max. diameter and 4.15 m overall height, including the lightning protection rod. Its base is in the form of a flange for mounting on top of a support tower. There are 32 holes in the flange, on the perimeter of a circle, allowing installation adjustment in steps of 11½°, or half the dipole spacing. A plan view of the antenna configuration is illustrated in Figure 11.1, showing the network of tension cables which form the ground plane of the array.

Figure 11.2 shows an elevation cross section of the antenna with its principal dimensions.

11.2 DF Receiver/Processor

The Receiver/Processor Unit is a top-of-the-bench mounted cabinet, 737 mm high, 535.5 mm wide and 432 mm deep. It contains five basic sub-units:

(1) Antenna Commutator which is a shielded enclosure, top-rack mounted, for easy access to the antenna terminals.

(2) DF Receiver, 19" rack unit, mounted in the lowest front panel position.

(3) The digital Bearing Processor and antenna switch control unit, a 19" rack unit, mounted in the top front panel position. This unit also has provision for the optional omni-directional monitoring facilities (audio and emergency).

(4) Receiver Control/Display unit, a 19" rack assembly, located in the centre front panel position for optimum ergonomics.

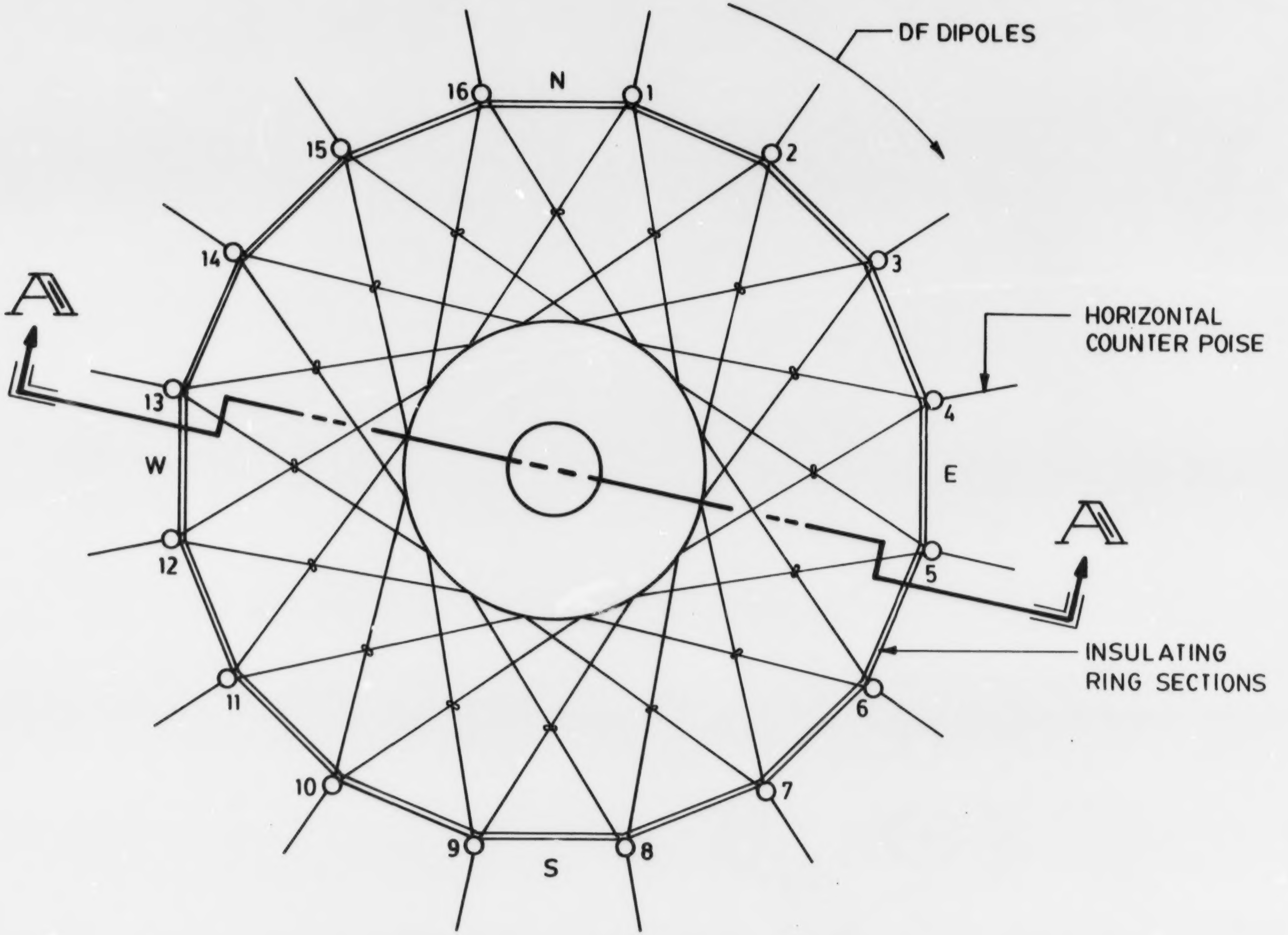
(5) Power supply assembly, mounted on the rear panel and hinged to open for ease of access.

A perspective presentation of the Receiver/Processor Unit is shown in Figure 11.3.

11.3 Operator's Control/Display Unit

A perspective view of the Operator's Control/Display Unit is shown in Figure 11.4, as used for insertion in the console front panel. The unit is of standard 19" rack type construction with an easily removable front panel for maintenance purposes, designed to give frontal access to the circuit modules. Its overall dimensions are 482.6 mm x 133.4 mm front panel and 300 mm depth.

This unit can also be housed in a bench-top cabinet of standard 19" rack type.


DF DIPOLES
N
16
1
15
2
14
3
A
HORIZONTAL COUNTER POISE
13
4
W
E
A
12
5
INSULATING RING SECTIONS
11
6
10
7
9
8
S

FREQ. RANGE: 117.5MHz - 136.5MHz
NO. OF DIPOLES: 16
ARRAY DIA: 3.750m REF

FIGURE 11.1

DF Antenna Array

Plan View of Ground Plane

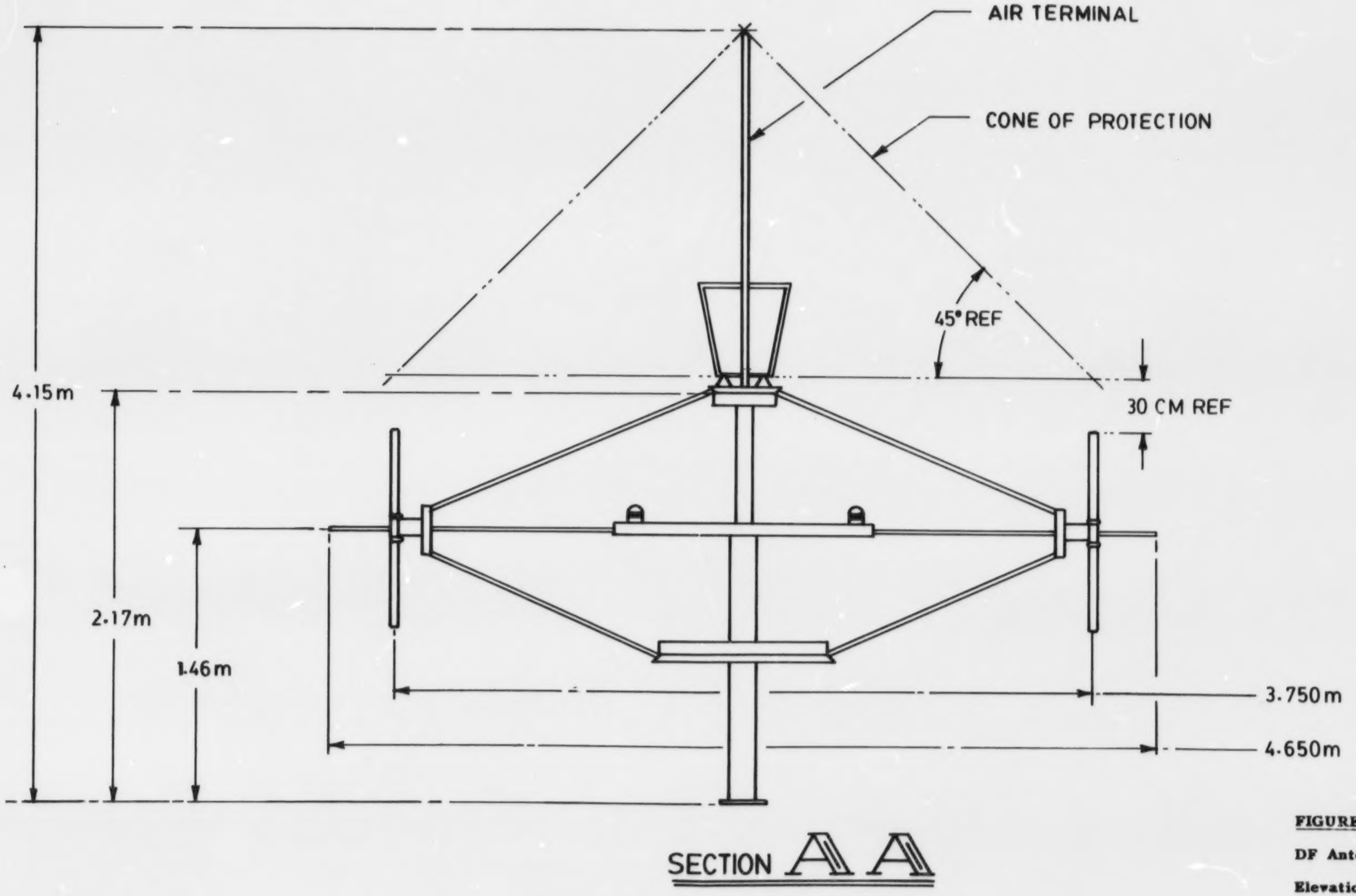

AIR TERMINAL
CONE OF PROTECTION
45° REF
30 CM REF
4.15m
2.17m
1.46m
3.750m
4.650m
SECTION AA

FIGURE 11.2

DF Antenna Array

Elevation Cross Section

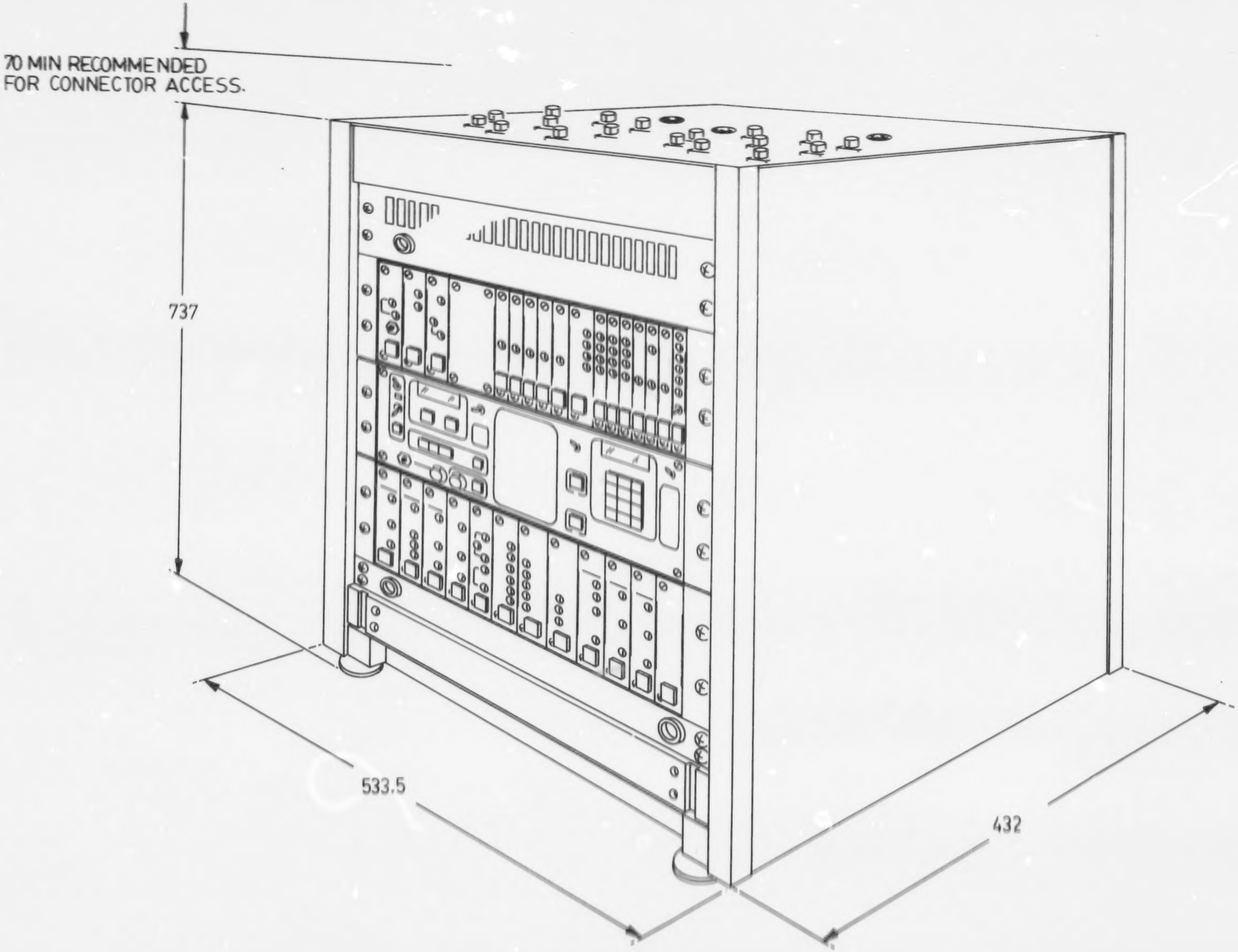

70 MIN RECOMMENDED
FOR CONNECTOR ACCESS.
737
533.5
432

FIGURE 11.3

Receiver/Processor Unit

Perspective View

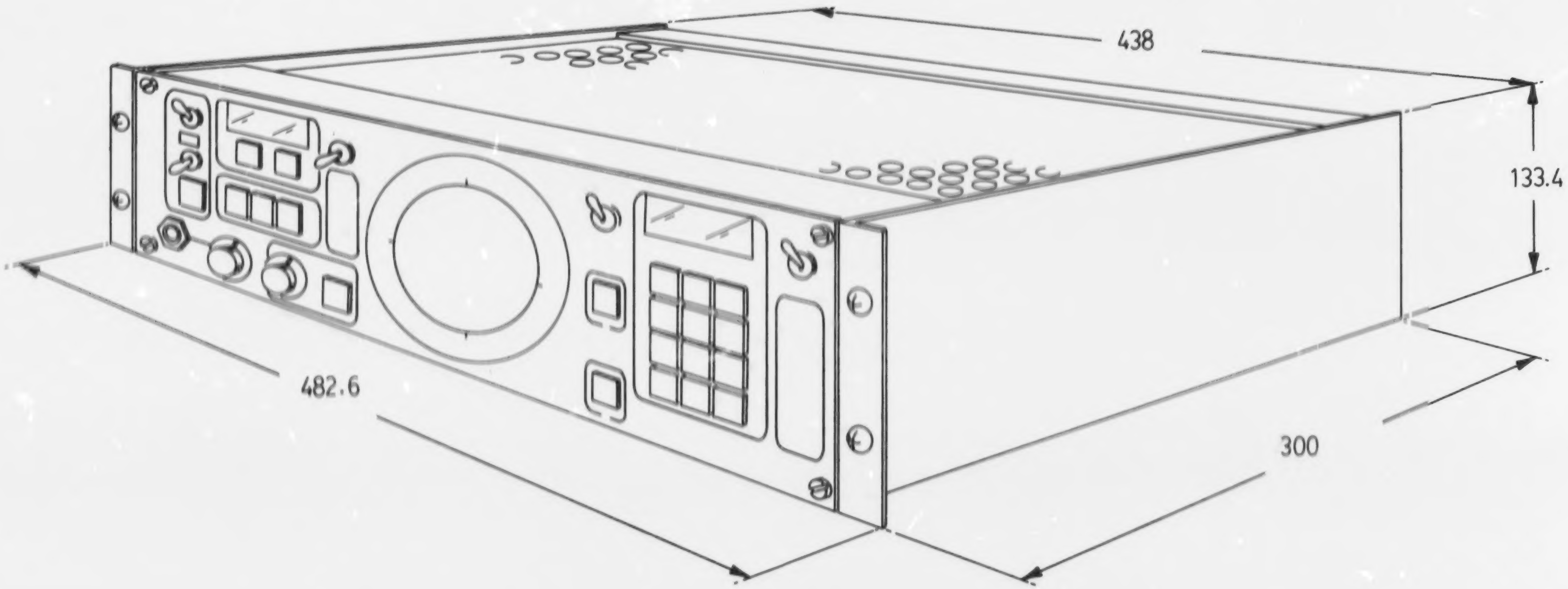

438
133.4
482.6
300

FIGURE 11.4

Operator's Control/Display Unit for Mounting in the ATC Console

APPENDIX 9

INTERIM TECHNICAL REPORT

PHASE I - DESIGN, SEPTEMBER 1981 to APRIL 1983

AUGUST 1983

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Appendices

Appendix 1 - PROJECT PLANNING DOCUMENTS

Appendix 2 - SYSTEM SPECIFICATIONS

Appendix 3 - DESCRIPTION OF THE DESIGN CONCEPT

Appendix 4 - DRAWINGS

Appendix 5 - APPENDICES - COPIES OF MONTHLY REPORTS

INTRODUCTION

This Interim Report provides the information on the project, up to April 1983. Every attempt has been made to provide all the documentation generated on the project, in particular, the drawings for the antenna.

1.0 BRIEF DESCRIPTION OF WORK CARRIED OUT

The work carried out during the period September 1981 to April 1983 is summarized as follows:

1.1 Prepared, and submitted to TDC, a detailed work plan, schedule, cash flow and management control plan (Item 4.1, Appendix 'A').

1.2 The Preliminary Specifications have been reviewed and Design Specifications finalized (Item 4.2, Appendix 'A').

1.3 Design and development on the following sub-systems has been started and completed:

(a) 32 Element Antenna Array

(b) Frequency Synthesizer

(Item 4.3, Appendix 'A')

1.4 The long lead component have been identified and purchased (Item 4.4, Appendix 'A').

1.5 The design changes, based on the results of field tests on the ATC DF System, have been identified and submitted to TDC (Item 4.5, Appendix 'A').

1.6 The construction of the prototype frequency synthesizer model has been started, however, during the evaluation of the performance, the unit did not meet the specifications, and work has been suspended. The antenna dipole has been built and tested, with satisfactory results (Item 4.6, Appendix 'A').

1.7 The work on the project was suspended during the early part of 1982.

SUMMARY OF APPENDICES

Project Planning Documents

The documents are enclosed herewith, see Appendix 1.

System Specifications

The final revision of the specification is enclosed herewith, see Appendix 2.

Description of the Design Concept

A detailed description of the design concept, including a detailed antenna analysis, is covered in Appendix 3.

Drawings

A set of drawings for the antenna, and circuit diagram for the frequency synthesizer, is provided in Appendix 4.

Monthly Reports

Copies of monthly reports are provided in Appendix 5.

APPENDIX I

PLANNING DOCUMENTS

MARINE DOPPLER RADIO DIRECTION FINDER
PROJECT STATUS - AUG.25, 1982

SUB-SYSTEMS	STATUS		RECOMMENDATIONS (REQUIRING CONTR. AMENDT)		
ANTENNA ARRAY	DESIGN TO BE COMPLETE SEPT 22, 82 READY FOR REVIEW				
ANTENNA DIPOLES	DESIGN NOT STARTED (ASSUME S. SEPT. 1ST - COMPL. NOV.)				
ANTENNA SWITCHING	MODULES FROM ATC TO BE USED; BASIC DESIGN COMPLETE	SOFTWARE CHANGE REQ'D TO TIMING CCT			
DF RECEIVER	DESIGN OF NEW FILTERS NOT STARTED; REQUIRES MECHN'L RE-PACKAGE				IMPROVEMENT OF MAINTAINABILITY & TROUBLE SHOOTING OF THE SYSTEM
BEARING PROCESSOR	DESIGN COMPLETE REQUIRES SMALL S/W CHANGE TO ACCOMODATE	32 ELEMENT SWITCHING	PROP. RE-DEVELOPMENT USING SINGLE MICROPROCESSOR	RESEARCH INTO IMPROVEMENT IN NOISE ENVIRONMENT	
AUDIO RECEIVER	DESIGN COMPLETE EXCEPT FOR INPUT FILTER		PROPOSE RE-DEVELOPMENT TO REDUCE COST		
EMERGENCY RECEIVER	DESIGN COMPLETE EXCEPT FOR INPUT FILTER		PROPOSE RE-DEVELOPMENT TO REDUCE COST		
FREQUENCY RECEIVER	NEW DESIGN REQUIRED (NOT STARTED)				
CONTROL CONSOLES	COMPLETE AS FOR ATC	MINOR CHANGE REQUIRED TO THE FREQ PROGRAM			
TEST INJECTION	BASIC DESIGN SAME AS ATC; SHEILDING IMPROV'TS REQ'D				

PHASING

(OR STEPS IN THE OVERALL PROJECT)

PHASE 1	PHASE 2	PHASE 3	PHASE 4	FOLLOW-ON PROJECTS	
PROJECT PLANNING & DESIGN	PROTOTYPE CONSTRUCTION & INPLANT TESTING	TESTING & DEBUGGING AT ANTENNA TEST RANGE	DOCUMENTATION & REPORTING	INSTALLATION & DEBUGGING AT OP'L TEST SITE (HALIFAX) (SEPARATE CONTRACT)	OPERATIONAL TESTING 1-YR (HALIFAX)
DELIVERABLES	DELIVERABLES	DELIVERABLES	DELIVERABLES	DELIVERABLES	DELIVERABLES
ACTIVITY NETWORK (WORK PLAN)	DETAILED DESIGN DRAWINGS	PROTOTYPE ANTENNA UNIT	PROD'N DWGS (3 COPIES)	INSTALLED EQPT.	TECH. SUPPORT AS REQ'D (BAYLY)
CASH FLOW CHART	PROTOTYPE ELECTRONICS UNIT	DEMONSTRATION OF PERFORMANCE TO TRANSPORT CANADA REPS	OPERATORS MANUAL (3 COPIES)	TEST REPORT	REPORT OF RESULTS (T & E MARINE)
PROJECT ORGANIZATION DIAGRAM	REPORT OF TEST RESULTS IN MONTHLY PROGRESS REPORTS	REPORT OF TEST RESULTS (APPENDED TO MONTHLY PROGRESS REPORTS)	TECHNICAL REPORT (30 COPIES)	OPERATOR TRAINING	
RAC MATRIX (RESPONSIBILITY, AUTHORITY, COMM'NS) (ROLES OF PARTICIPANTS)					
APPROVED DESIGN SPEC'N FINAL SPEC'N (INCL. SIGN-OFF)					
LIST OF LONG LEAD TIME COMPONENTS (COST & DELIVERY) $32,000.+/-					
DESCRIPTION OF PROPOSED DESIGN CHANGES FROM ATC UNIT					
PRELIMINARY DESIGN DWGS					
MONTHLY PROGRESS REPORTS	MONTHLY PROGRESS REPORTS	MONTHLY PROGRESS REPORTS	MONTHLY PROGRESS REPORTS	MONTHLY PROGRESS REPORTS	QUARTERLY PROGRESS REPORTS

MARINE DOPPLER RADIO DIRECTION FINDER / TDC 7420

AUG 82

PROJ WEEK	CALENDAR WEEK
1	22-28
	-
	-
	-
	-

SEPT 82

PROJ WEEK	CALENDAR WEEK
2	29- 4
3	5-11
4	12-18
5	19-25
6	26- 2

OCT 82

PROJ WEEK	CALENDAR WEEK
7	3- 9
8	10-16
9	17-23
10	24-30
	-

NOV 82

PROJ WEEK	CALENDAR WEEK
11	31- 6
12	7-13
13	14-20
14	21-27
	-

DEC 82

PROJ WEEK	CALENDAR WEEK
15	28- 4
16	5-11
17	12-18
18	19-25
19	26- 1

JAN 83

PROJ WEEK	CALENDAR WEEK
20	2- 8
21	9-15
22	16-22
23	23-29
	-

FEB 83

PROJ WEEK	CALENDAR WEEK
24	30- 5
25	6-12
26	13-19
27	20-26
	-

MAR 83

PROJ WEEK	CALENDAR WEEK
28	27- 5
29	6-12
30	13-19
31	20-26
32	27- 2

APR 83

PROJ WEEK	CALENDAR WEEK
33	3- 9
34	10-16
35	17-23
36	24-30

MARINE DOPPLER RADIO DIRECTION FINDER / TDC 7420

MAY 83		JUNE 83		JULY 83	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
37	1- 7	41	29- 4	46	3- 9
38	8-14	42	5-11	47	10-16
39	15-21	43	12-18	48	17-23
40	22-28	44	19-25	49	24-30
	-	45	26- 2		-

AUG 83		SEPT 83		OCT 83	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
50	31- 6	55	4-10	59	2- 8
51	7-13	56	11-17	60	9-15
52	14-20	57	18-24	61	16-22
53	21-27	58	25- 1	62	23-29
54	28- 3		-		-

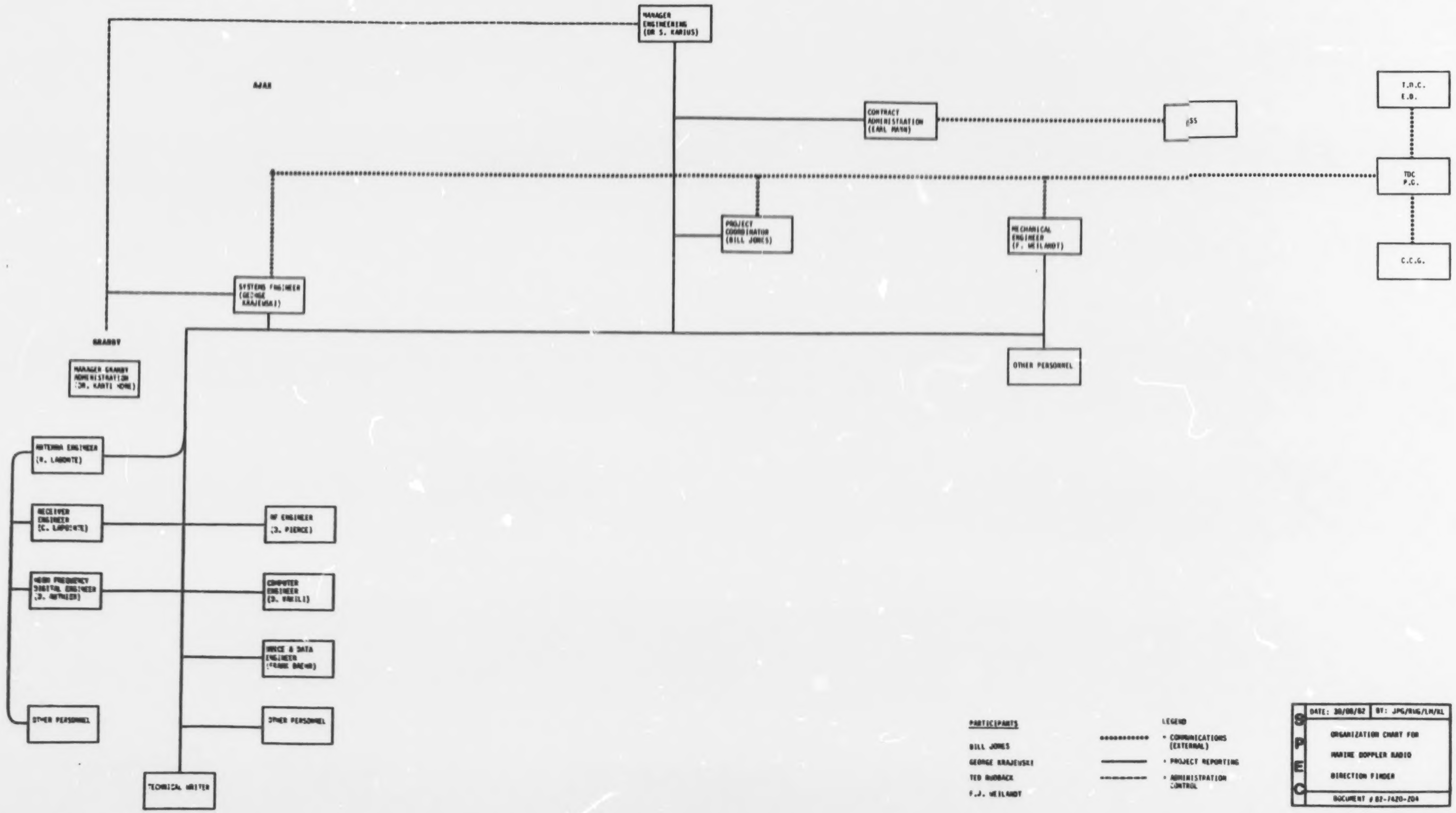
NOV 83		DEC 83		JAN 84	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
63	30- 5	68	4-10	72	1- 7
64	6-12	69	11-17	73	8-14
65	13-19	70	18-24	74	15-21
66	20-26	71	25-31	75	22-28
67	27- 3		-		-

MARINE DOPPLER RADIO DIRECTION FINDER / TDC 7420

FEB 84		MAR 84		APR 84	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
----	----	----	----	----	----
76	29- 4	81	4-10	85	1- 7
77	5-11	82	11-17	86	8-14
78	12-18	83	18-24	87	15-21
79	19-25	84	25-31	88	22-28
80	26- 3		-		-

MAY 84		JUNE 84		JULY 84	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
----	----	----	----	----	----
89	29- 5	94	3- 9	98	1- 7
90	6-12	95	10-16	99	8-14
91	13-19	96	17-23	100	15-21
92	20-26	97	24-30	101	22-28
93	27- 2		-		-

BAYLY ENGINEERING LTD
MARINE DOPPLER RADIO DIRECTION FINDER
PROJECT ORGANIZATION CHART


MANAGER ENGINEERING (DR S. KARIUS)
AJAX
CONTRACT ADMINISTRATION (EARL MANN)
DSS
T.D.C. E.D.
TDC P.C.
C.C.G.
PROJECT COORDINATOR (BILL JONES)
MECHANICAL ENGINEER (F. WEILANDT)
SYSTEMS ENGINEER (GEORGE KRAJEWSKI)
GRANBY
MANAGER GRANBY ADMINISTRATION (DR. KANTI HORE)
OTHER PERSONNEL
ANTENNA ENGINEER (R. LABONTE)
RECEIVER ENGINEER (C. LAPOINTE)
HIGH FREQUENCY DIGITAL ENGINEER (J. AETHIER)
OTHER PERSONNEL
RF ENGINEER (J. PIERCE)
COMPUTER ENGINEER (D. VASILI)
VOICE & DATA ENGINEER (FRANK BREHM)
OTHER PERSONNEL
TECHNICAL WRITER

PARTICIPANTS

BILL JONES
GEORGE KRAJEWSKI
TED RUDBACK
F.J. WEILANDT

LEGEND

••••••••••• - COMMUNICATIONS (EXTERNAL)
——————— - PROJECT REPORTING
- - - - - - - - ADMINISTRATION CONTROL

S P E C
DATE: 30/08/82
BY: JPG/RWG/LM/RL
ORGANIZATION CHART FOR
MARINE DOPPLER RADIO
DIRECTION FINDER
DOCUMENT # 82-7420-204

APPENDIX 2

APPENDIX 3

SYSTEM SPECIFICATIONS

DESCRIPTION OF THE DESIGN CONCEPT

DESIGN IMPROVEMENTS

BAYLY
ENGINEERING
LIMITED

PROPOSAL

DEVELOPMENT AND CONSTRUCTION OF A PROTOTYPE QUASI-DOPPLER MARINE VHF RADIO DIRECTION FINDER

Prepared by: Z.A. Krajewski
June 20, 1981

RESTRICTION/PROPRIETARY INFORMATION

The contents of this Unsolicited Proposal embody information of proprietary nature, describing application of Patents owned by this firm, and discloses ideas which will further lead to patentable inventions.

This information shall not be transmitted or communicated to any persons outside the addressee without the Company's writen consent.

BAYLY
ENGINEERING
LIMITED

PROPOSAL

DEVELOPMENT AND CONSTRUCTION OF A PROTOTYPE

QUASI-DOPPLER MARINE UHF RADIO DIRECTION FINDER

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1.0 GENERAL

1.1 Summary

Doppler-type Radio Direction Finding has been recognized for a long time as a practical navigational aid for the control of air traffic and marine navigation. Existing sources and equipment from outside Canada employ techniques in use for many years. It is proposed here to develop a state-of-the-art Canadian Quasi-Doppler Marine VHF Radio Direction Finder aiming at better DF accuracy, a more reliable design, and yet less expensive to manufacture than the equipment presently available.

The following technical description demonstrates how this can be achieved.

1.2 Background

Bayly Engineering is presently engaged in developing an improved Doppler type radio direction finder for use in air traffic control (ATC) applications. This project is supported at 80.1% by a contract from Transport Canada R and D Centre, which was obtained as a result of an unsolicited proposal submitted to the DSS Science and Procurement Centre in August 1979. Development of the ATC equipment is close to completion, evaluation of the prototype being scheduled for September next.

The experience gained during this development can now be utilized to develop and construct a similar direction finding system for marine applications where more stringent requirements for accuracy and reliability must be met. Some thought was already given to this matter in the original development of the ATC system where the basic design was made compatible with the marine concept so that only certain modular components will have to be substituted for the new application.

This proposal is an updated version of the Phase II extension proposed in Appendix A of the Unsolicited Proposal dated August 22, 1979. Revisions have been made, where necessary, regarding technical status, schedules and cost estimates.

1.3 Scope

It is proposed to develop and build a new state-of-the-art Quasi-Doppler radio direction finder for marine applications which will provide greater bearing accuracy and higher reliability at lower cost as compared with equipment presently available. The equipment is to be used in fixed land-based installations in the marine frequency band of 156-162 MHz using vertical polarisation.

2.0 TECHNICAL DESCRIPTION

2.1 Introduction

Early Doppler DF, dating back to the Second World War, used a physically rotating antenna pair producing a signal which was frequency modulated at the rate of the rotation of the antenna. A phase of this FM is related to the angular position of the target and can be detected with reference to a given azimuth point, e.g. the North. In later developments, antenna rotation was replaced by sequential switching of a series of fixed dipoles arranged in a circular array.

The advantage of the Doppler principle lies in the relatively large aperture of the antenna which is of the order of one to several wavelengths. The larger the relative aperture, the smaller are the errors due to local reflections of the received signal. Large apertures, on the other hand, necessitate increased numbers of switched elements and a more elaborate commutating system, resulting in higher costs. For navigational aids, it is usual to compromise, giving the required bearing accuracy of 1° or better at minimum cost.

Doppler DF Systems present problems inherently bound with their method of operation:

1) The bearing tends to fluctuate with frequency modulation of the signal either by the superimposed intelligence or by noise.

2) The detection of modulated intelligence becomes difficult in the presence of the simulated antenna rotation switching.

3) The response time is not negligible, since multiple rotations of the antenna have to be integrated to evaluate the DF data.

4) Intermodulation products are generated at the antenna commutation interface. They appear as FM sidebands and may have enough amplitude to splash over into the adjacent channels.

The new design is aimed at improving the solutions to the above problems by introducing several novel approaches.

2.2 The New Doppler DF System

The new Doppler DF System is proposed for fixed land-based installation, to operate in the marine navigation range of 156-162 MHz. The system comprises a stationary circular antenna array, a remote receiver unit and a local display/control unit. The antenna and the receiver unit are connected with a set of RF cables of up to 50 m in length and the receiver is linked to the display/control unit by means of a standard 4-wire telephone link.

Two optional features are available with the main system:

1) Facility to demodulate the VF intelligence of the incoming signal (AM or FM detectors) and to transmit it to the display/control unit.

2) Emergency call facility, operating on 121.5 MHz or 223 MHz, to override temporarily the normal operation of the system.

The Marine Navigation requirements differ from those for Air Traffic Control in that the VF modulation detection is often not required. The audio facility may be omitted with a reduction of cost. Although different frequency bands are used for the two applications, the system design remains the same, the difference being covered by changing antenna dimensions and replacing certain plug-in filter and oscillator modules.

2.3 Principle of Operation

The Doppler antenna consists of a number of vertical dipoles tuned to the top of the frequency band and spaced equally in a circle. All the dipoles are connected with equal length cables to the commutator located in the centre hub. In the new design, two adjacent dipoles are sampled simultaneously, the pair being switched round the circle at a rate set by the commutation generator. The voltages induced in the sampled pair remain almost constant but their relative phase undergoes cyclical variation as the switching progresses through 360°. This phase can be measured continuously after the two signals are processed through two identical receiver channels, each consisting of RF amplifiers, frequency converters and i.f. stages.

The Comparator operates at the final intermediate frequency and produces an output of a pulsed waveform superimposed over a sine function. It is the positive-slope zero crossing of this waveform which determines the angular position of the target.

To determine this position accurately, the Phase Comparator output must be digitized and then processed using a Fourier Transform to reduce it to a pure sine wave, the phase of which must be compared with that of North reference signal supplied directly from the commutation generator. A fine North setting adjustment is provided by the Reference Control. The Bearing angle is obtained by counting the time with a clock frequency set to 1/3600 of the commutation frequency. A digital bearing readout is obtained in steps of 0.1°, indicated digitally on the Remote Bearing Indicator. The bearing readout can be reversed by 180° by operating the Bearing/Heading Control Line. The Heading mode is shown by an Indicator Light beside the angle data. A variable integration constant is provided in the Bearing Processor, enabling the operator to set an optimum compromise between the signal quality and speed of response. In addition to the digital bearing display, an analog display is provided by means of an array of 72 LED's arranged around a compass circle.

2.4 Fundamental Advantages

By sampling two instead of one dipole, the restrictions are removed on the aperture of the array - there being no ambiguity of bearing as the diameter becomes larger than the wavelength. The same system design may be used with different sizes of arrays, say with 16 elements and 32 elements. The choice depends on a compromise between the cost of the antenna and the immunity to local reflection errors. For a bearing accuracy of ±0.5° in marine applications it is recommended to use 32 elements on a circle of approximately 3λ diameter.

Speed of commutation is no longer critical. There is no need to ensure a frequency deviation large enough in comparison with the stability of the carrier. The only criterion is that of the bearing response time. A rotation frequency of about 80 Hz would provide a bearing reading averaged over 8 cycles in 0.1 second. A low commutating frequency has the advantage of less interference with the audio reception. Furthermore, the splash-over of intermodulation products into the adjacent frequency channels is also reduced.

The two i.f. channel voltages are similar in amplitude and contain equal percentages of AM or FM and an equal share of atmospheric noise. By measuring their relative phase any modulation or noise effect is reduced to negligible proportions. Moreover, the phase comparator need not be precise, or even linear, since it is the cyclical waveform of the phase output which contains the azimuth information and not its amplitude.

The phase comparator operates throughout each period of dipole pair sampling so that there is no waste of real time in receiving the azimuth information. The system is thus more immune to noise and pulse interference.

The system is capable of expanding to a wide-band operation by adding lower frequency ranges with the same antenna array and without substantial loss of sensitivity. This can be simply done by sampling antenna pairs spaced two or three apart, etc., so as to maintain an optimum phase difference at increased wavelengths. The limit of spacing is obviously set by the diametrical pair of dipoles.

2.5 Receiver Channel Commutation

The accuracy of phase measurement with a twin channel receiver depends on the precision with which the two channels can be matched in phase over the bandwidth and over their dynamic range. This precision depends largely on the type of filter used in the final i.f. stages.

The phase (and hence bearing) errors due to channel mismatch are eliminated by periodically interchanging the receiver channels and averaging the results. This method was used successfully in Watson-Watt type of direction finders, such as Telegon IV, VI and others. Both inputs and outputs have to be commutated simultaneously, where the input switching can be made integral with the antenna selection. Thus, for each antenna step there will be two receiver switching steps: one with the two channels connected directly, and one with the channels interchanged.

The total number of switching steps for one antenna rotation becomes 2n where 'n' is the number of antenna elements. The phase fluctuations due to channel mismatch are hence smoothed out together with the progression of antenna steps, giving a final phase waveform approximating a sine wave.

2.6 Adjacent Channel Interference

Commutation of the antenna elements is conventionally done with a diode matrix. In this case each antenna element must be able to select one of three paths:

i) input of receiver channel 1

ii) input of receiver channel 2

iii) a dummy load

The matrix is programmed to advance the sampled pair of elements step by step around the circle, each step operation being performed first with normal and then with reversed receiver channels.

The switching function of the antenna elements is very critical. Multiple sideband spectra of intermodulation products can be caused by abrupt non-linearities. Unless suitably suppressed, the sidebands can splash over into the adjacent frequency channels causing false alarms in the presence of strong adjacent signals. By means of 'soft' switches, the switching function is shaped for optimum splash sideband suppression within the desired bandwidth.

The antenna commutation matrix is in modular form, the basic module being equivalent to an 8-pole, 3-way switch to provide scanning for an 8-element antenna. By interconnecting two or four such modules, scanning can be provided for antennas of 16 or 32 elements respectively.

2.7 Immunity from Site Errors

The size of the antenna is decided by the site conditions and the desired accuracy of bearing in the presence of stationary of moving objects in the vicinity of the antenna tower. The immunity from errors caused by reflections from such objects ia a function of antenna aperture and hence the number of antenna elements. While 16 elements (antenna array diameter of 1.5) may be satisfactory for airports with a clear site, a 32 element antenna (diameter of 3λ) will be necessary for marine applications.

2.8 Cancellation of Group Delay Error

Direction Finders with rotating antennas have to be compensated for the zero reference offset resulting from a finite time the signal takes to travel through the receiver. Conventionally, this is done by adjusting the phase of the reference voltage from the generator of the antenna commutation frequency. This compensation can only be true at the centre frequency of the final i.f. filter. It can seriously deviate from the required value if the transmitter frequency is drifting either due to its stability or the movement of the target. Some improvement may be reached by tracking the transmitter with the AFC, but only when the transmitted spectrum is symmetrical or when a strong carrier is present.

A new method of cancelling out the group delay error is adapted by consecutive sampling of the antenna array with two rotation frequencies ω_1 and ω_2 for respective numbers of consecutive terms of m and n.

It can be shown that complete cancellation of the error is obtained by selecting:

$$\omega_1/\omega_2 \quad = \quad n/m \text{ and } n - M = 1$$

In practical terms, for a 32 element antenna f_1 can be made 108 Hz and f_2 = 81 Hz ($n/m = 4/3$).

The complete minimum sampling cycle may thus constitute 4 revolutions at 81 Hz followed by 3 revolutions at 108 Hz. The bearing is computed at the end of the total sampling time of approximately 0.1 sec.

Longer integration times, 0.2 sec., 0.4 sec., or 0.8 sec., are provided by multiplying the numbers of revolutions by the appropriate factor.

2.9 Interference Flicker

In the described dual frequency method the scanning frequencies ω_1 and ω_2 are derived by division from the same master scan generator using two consecutive division ratios. Thus 81 and 108 Hz may be obtained by dividing a common frequency source of 324 Hz by 4 and 3 respectively.

Now, the master scan oscillator frequency can be made variable without affecting the operation of the system, since ω_1 and ω_2 will always be related in the manner required to cancel the group delay error and there are no other frequency sensitive elements in the bearing processor. The operator will be able to set his master scan frequency so as to avoid interference with modulation patterns of the received signal or with low-frequency EMI which may be locally present.

It is believed that the quoted dual frequency scanning method is the only one offering this advantage.

2.10 Separate Audio Channel

A separate antenna, located at the electrical centre of the array is connected to another receiver channel tuned to the same frequency as the two Doppler channels. The i.f. portion is provided with AGC and terminates in either one of two demodulators: FM or AM. Re-radiation of the commutation pulses from the DF dipoles is reduced by keeping this antenna separate and somewhat elevated with respect to the plane of the array. The audio output of this receiver can be monitored in the remote unit and is further available for transmission to the local unit.

Since the FM cancellation for DF no longer depends on the signal from the centre antenna, the entire audio channel can be left out if this facility is not required.

2.11 Transmission of Audio and DF Data

The DF information and the output from the audio channel are transmitted to the Local Control/Display Unit by means of a standard 600Ω, 4-wire telephone cable. For this purpose, it is necessary to provide a set of 'data above voice' modems. The digital bearing data, and any other bits of information, such as the 'data valid' signal derived from the S/N detector are converted from parallel to series mode and applied to modulate an FSK transmitter, operating in the 2.4 - 3.0 kHz band. The remaining portion of the spectrum (300 - 2300 Hz) is utilized to transmit the audio intelligence. Some 32 bits of information are necessary so that the time required for the data to pass need not exceed 0.1 second.

At the Local Control/Display end the audio and data signals are separated and converted back to parallel mode for display at the local bearing indicator. A memory unit is available for storing the incoming data until it is cancelled by the operator. In an automatic emergency mode the first valid reading of the emergency transmission is stored.

A 'system alarm' is provided, indicating a break of transmission from remote to local or a power failure at the remote end. This operates on detecting the presence of the FSK carrier from the 'data above voice' modem. A 'remote control' indicator lights up when the system is operated manually from the remote end.

An amergency indicator shows when the DF receiver has been switched over to the emergency channel band.

2.12 Remote Control from the Local Unit

Another 'data above voice' modem is used to transmit control information to the remote unit and to the antenna head. This includes:

Channel selection (10 preset channels + EMERGENCY)

Bearing/Heading selection

Remote Power ON/OFF

Integration constant (4 positions)

Antenna Test Injection ON/OFF (test facility option)

Emergency auto-manual (emergency call option)

Dual or multiple control/display facilities can be made available.

2.13 Synthesized Local Oscillator

The local oscillator in the Receiver Unit is of the phase lock loop type, locked to multiples of 25 kHz, so that selection of the tuning frequency is obtained by programming the frequency dividing counters. Stability is ensured by deriving the 25 kHz source from a temperature compensated master crystal oscillator. Up to 10 pre-programmed channels are available and the programming is made directly on the circuit board. A limited range of AFC facility is provided to lock onto the transmitter frequency and to ensure accurate tuning to the centre of the i.f. in case of transmitter drift.

In addition to the 10 preset channels and the emergency channel there is also an option for direct frequency dialing. The operator can select any frequency inside the band (in 25 kHz steps) by punching the six consecutive digits on the control/display unit. The receiver replies by transmitting code pulses to indicate the frequency chosen.

2.14 Emergency Channel

In this option emergency call signals at any pre-selected emergency frequency within the band will be monitored by the centre antenna and processed via a separate emergency receiver with fixed tuning, terminating in a detector, the output of which will respond to the emergency condition.

In accordance with operational requirements for Vessel Traffic Management Systems, two modes of Emergency Channel are provided.

Mode 1 - Fully Automatic

In the AUTO position, detection of an emergency signal automatically switches the DF Receiver to the emergency frequency to give a bearing on the target in distress and to send the bearing data to the local site. The emergency channel light is turned on. The first valid reading is stored and displayed on the stored bearing readout. A long release time constant ensures capture of even brief pulsed signals. On cessation of the emergency signal, the DF receiver reverts to the original frequency but the stored bearing remains on the display unit until it is reset by the operator.

Mode 2 - Manual

In this mode the MAN-AUTO switch is placed in the MAN position. The emergency receiver output is disregarded. Changeover of the DF receiver to the emergency channel has to be done manually.

2.15 Built-in Test Facilities

Accuracy and alignment of the DF section can be tested in absence of a transmitting target by means of the antenna test injection synchronized with the commutation frequency. A set of four artificial bearing readouts is generated, selectable from the local control unit. This facility is optional.

Taking advantage of the built-in 'data above voice' modems, a service telephone facility is provided to link the local and the remote sites by using standard 2-wire telephone sets (not provided). The 2-wire/4-wire hybrids are substituted for the audio channel as the telephone set is inserted in the service jack.

2.16 Interconnections

The Antenna Head is connected to the Remote Unit by means of a multi-core control cable and four double-shielded coaxial cables, one of which may be omitted, if the audio and the emergency call facilities are not needed. The length of this connection should not exceed 50 m on account of extra losses and possible interference pick-up.

The Remote-Local link consists of a standard telephone wire quad, preferably in the form of a buried cable. Cl grade characteristics are advisable to avoid losses at the data transmission frequencies. Up to 10 Km distance is envisaged which can be extended by the addition of standard telephone repeaters. An alternative Local-Remote link for short distances up to 100 m is available as an option consisting of a multicore control cable with the omission of the 'data above voice' modems.

2.17 Construction

Emphasis is placed on modularity to achieve a low mean-time to repair figure. Modular approach also provides flexibility to provide different options to suit particular customer applications.

The Antenna Head consists of a central hub with detachable identical dipole arms, the hub being supported by a tuned section of tubular mast which carries the interconnecting cables inside it. The hub also carries a waterproof cabinet with waterproof doors to give access to a number of plug-in modules comprising the commutator and the RF Heads. The aircraft warning lights are placed directly above the hub, with the centre antenna directly above. Provision is made for attaching a lightning conductor in the centre of the array.

Both the Remote Receiver and the Local Control/Display Unit are designed in standard 19" 'Intermas' rack housings, with plug-in modules using the standard 'Eurocard' 100 x 160 mm or 100 x 220 mm printed circuit boards. Replacement interchangeability of all the boards is ensured. All controls and indicators are brought over to the front panels as well as the telephone and test jacks. The power and inter-unit wiring is from the rear of the equipment.

2.18 Summary of Innovations

In the new Doppler DF System there are several new concepts, either based on original inventions or on the application of known technology not previously employed in this field. Some of these concepts are already patented by this Company, others may be patentable. The following list summarizes the innovations with reference to the description in text:

1) Simultaneous sampling of two dipoles on the circumference of the antenna array (para 2.3)

2) Signal processing by digital frequency analysis (para 2.3)

3) Elimination of the twin channel receiver unbalance by means of channel commutation (para 2.5 Telefunken patents)

4) Cancellation of group delay error by dual frequency of antenna rotation (including provision of variable scan frequency). (paras 2.8 and 2.9 - Bayly patents)

5) Tracking of the transmitter frequency by an AFC network to allow for a narrow-bandwidth reception (reduced noise) of transmissions with poor frequency stability or from moving targets. (para 2.13)

3.0 AREAS OF NEW DEVELOPMENT

3.1 Requirements for Marine Applications

A substantial part of the development of the DF System is already covered in the development of the ATC prototype under the present contract. This proposal is concerned with the development of those sections or modules which differ from the ATC version either due to different tuning range, improved accuracy, or on account of different custom interface requirements.

Such additional development is limited to antenna design, the receiver front end, the frequency synthesizer, the bearing processor and the control/display interface.

3.2 Antenna

The principle of 2-element sampling and dual speed scanning of the antenna will remain in force also in the Marine version but the antenna dimensions will be scaled down in proportion to the wavelength so as to adapt it for operation in the 156-162 kHz band. Thirty-two (32) elements will be used in the antenna array in order to give the best possible reduction in re-radiation errors. The solid-state commutator developed for ATC will be expanded retaining the special features of suppressing the intermodulation sidebands. The antenna will be constructed of modular components, similar in both systems even if the spacing and number of elements are not the same.

3.3 RF Circuits (Front End)

The receiver front end will be re-designed to accept the new band of frequencies which in practice reduces to substituting new RF bandpass filters. Oscillator buffers will also need to be retuned. Both of these parts are located in the antenna hub. RF amplifiers and mixers, being of wide-band design, will not require modification.

3.4 Frequency Synthesizer

A new frequency synthesizer will be developed for the marine tuning band. This will be in the form of a plug-in module replacing that used for the ATC band. The basic design will provide up to 240 channels to tune the receiver from 156 to 162 MHz. This may be extended later to 720 channels to allow for a wider market. Up to 10 pre-selected channels will be available by push-button selection from the 'local' control/display unit. The pre-selection will be accomplished by setting up the scaling counters on each channel board in the receiver unit. A direct frequency access facility will also be available in steps of 25 kHz.

3.5 Bearing Processor

The digital bearing processor will be adapted to sample pulse signals from 32 antenna elements. Both hardware and software development will be involved.

3.6 Control/Display Interface

Minor modifications may be necessary in the 'local' control and display unit in order to adapt it to control two 'remote' units and to interface with a cross-fix calculator for two-dimensional location of the target as outlined in the Statement of Work for the Coast Guard (November 24, 1979). This work will include additional buffer boards for the control terminals.

4.0 TARGET SPECIFICATION

4.1 DF System

Frequency Range : 156-162 MHz (marine navigation) compatible for extension to 174 MHz.

Principle of Operation : Large aperture (approx. 3.5 lambda) quasi-doppler with differential sampling of 32 antenna elements

System Accuracy : ≤0.5° with 32 antenna elements

RF Noise Figure : ≤ 7 dB

Polarization Error : approx. 1° with 45° tilt

Sensitivity (vertical polarization) : ≤ 3µV/m for ±1° accuracy

Antenna immunity to reflections as compared with Adcock DF : min. 16 times improvement with 32 elements

Group Delay Error : Cancelled out by dual rotation frequency

Antenna Scanning Frequency : Adjustable to clear interference flicker

DF Receiver Phase Match Error : Cancelled out by channel commutation

Mode of Operation : Continuous, unattended

Number of Frequency Channels (channel select mode) : 10 switch selected + emergency channel - each channel frequency programmable within the equipment

Direct Frequency Selection (frequency select mode) : Six digit dialing of any frequency within the band in multiples of 25 kHz

Channel Spacing : 25 kHz

Acceptance Bandwidth : approx. ±50ppm of the carrier frequency

Adjacent Channel Breakthrough : ≤ 1° error with adjacent channel signal up to 50 dB above wanted signal but not exceeding 3mV/m.

Bearing Indication - Digital : 4 digits with LED numerals. Provided at both local and remote units.

Bearing Indication - Analog : On the Operator's Control/Display Unit only, by means of a circular array of 72 LED indicators under a compass overlay. The analog bearing display can be preset on installation to correspond to the direction the operator is facing.

Sense Indication : Heading pushbutton and indicator light.

Response Time : 100 ms to 0.8 sec. depending on the setting of integration constant

Bearing Readout Update : Equal to integration constant

Valid Display Indication : Bearing display is blanked out if bearing data is not valid

Local Panel Controls and Indicators : Power on/off switch operated with a key

Dimmer
Lamp test
Remote power on/off switch
Master/Slave switch
Control active - indication light shows the local power is in control

System alarm indicator and reset

Freq. mode select/reset
Channel selection - 10 pushbuttons with indicators operated by feedback from remote
Frequency selection using the same pushbuttons in freq. select mode.
Frequency readout - six digit operating only in freq. select mode

Bearing store on/off and reset
Stored bearing indication (4 digits)

Overhead pass indicator light

Integration constant (4 positions 0.1 sec. to 0.8 sec.)
Scan frequency (3 positions)

Remote Panel Controls and Indicators	:	Power on/off switch operated with a key turns on complete remote station with antenna Receiver power on/off (remote control remains on for communication with local) Dimmer Lamp Test Local/Remote switch Control active - indicator light shows the panel is in control System alarm indicator and reset Freq. mode select and reset Channel selection - 10 pushbuttons with indicators Frequency selection using the same pushbuttons in freq. select mode Frequency readout - six digit display operating only in freq. select mode Bearing Indicator 4 digit LED display Overhead pass indicator light Integration Constant - 4 positions 0.1 sec. to 0.8 sec. Scan frequency (3 positions)
Auxiliary Data Output	:	At both local and remote units, TTL compatible parallel data bit format.
Auxiliary Channel Select	:	At the remote unit for control from another site
Squelch Threshold	:	Fully adjustable from receiver front panel of remote unit
Service Telephone	:	Jacks provided for 2-way communication between remote and local units (audio channel disabled)
Aircraft Warning Light	.:	Integrated with antenna structure (may be left out if not required)
Cables: Antenna Head to Remote Receiver	:	2 coaxial double shielded ½" and 1 multicore, 50 m max. RF connectors : N type
Remote to Local - Long Distance	:	4 wire telephone line - 10 Km max.
Short Distance option		multicore cable 100 m max.

4.2 **Multiple Control Stations** : Two or more local panel controls can be interconnected by switching at the 4-wire telephone line level.

4.3 Audio Monitoring Option

Monitor Antenna : Centre of the array

Frequency : Automatically tuned with the DF system

Receiver Sensitivity : 7 dB NF

Type of Detector: Option : either AM or FM as requested

Output : 0.5W loudspeakers output available on both remote and local units.

Auxiliary Output : 600Ω on both units

Squelch on/off : Provided on the Remote Unit

Squelch Adjustment : Provided on the Remote Unit

AGC : Provided on the Remote Unit

Volume Control : Individual volume controls on both local and remote units

Phone Jacks : Insertion of headphones disconnects loudspeaker output

Additional Cable

Antenna Head to Remote Receiver : Co-axial, double shielded, ½", 50 m max. (N-type connectors)

4.4 Emergency Call Option

Antenna : Common with audio monitoring provided with separator filter

Receiver Sensitivity : 7 dB NF

Tuning : Preset selectable to any channel within the RF band (156-162 MHz)

AGC : Pre-set on remote unit

Detector : Carrier presence above threshold pre-set at the Remote Unit

Additional Controls

AUTO-MAN : At both local and remote units

Emergency Channel Selection : LED pushbuttons and indicators at local and remote units

Additional Cable

Antenna Head to Remote Receiver : Co-axial, double shielded, ½" 50 m max. (N-type connectors)

4.5 System Test

Antenna Test Injection (System Test) : Provides selection of 4 simulated targets at 45°, 135°, 225°, and 270° locations

RF Test Source : Generates a synthetic RF signal by adding i.f. to the LO frequency (Antenna Unit)

Location : Four test injection monopoles situated in the Antenna Plane

Control : Pushbuttons from Local or Remote Units (Note: Normal operation is disengaged when operating the System Test)

4.6 Environment

Temperature Range Operational

Antenna : -55°C to +55°C
Local and Remote Unit : -20°C to +55°C

Humidity : 95% maximum

Wind Load (Antenna) : 160 Km/hr max.

Salt Spray (Antenna) : Equivalent to MIL specifications

Drip-proofing (Antenna) : Equivalent to MIL specifications

Ice Formation (Antenna) : Up to 1" thickness

5.0 DEVELOPMENT PROGRAM

5.1 Introduction

Within the scope of this project it is proposed to proceed with development of the special 32 element antenna and such other sub-systems for the marine application which are different from those developed for the ATC radio direction finder.

As soon as the results of the field tests are available on the ATC radio direction finder prototype, it is the intention to hold a design review meeting in order to identify possible problem areas and to plan for improvements which may be necessary to overcome any difficulties and which may also be applicable for the marine application.

At this point, the remainder of the forthcoming development will be defined and work can be released to build a complete marine doppler DF prototype.

Consideration will be given at an early stage of the project to identify and put on order any long-lead procurement items, so that the prototype assembly phase may not be delayed.

5.2 Task Definitions

Development of Marine-oriented Sub-systems

Development of the Marine Doppler DF System includes the following specialized tasks:

1) System refinement and confirmation of the specifications for the Marine DF application.

2) Antenna design for the marine navigation band with 32 antenna elements.

3) Re-design of the receiver front end filters and buffer amplifiers.

4) Development of a new frequency synthesizer for the 156-162 MHz range.

5) Adaptation of the control/display unit for the marine requirements. Development of additional buffer modules. Study of operation with a cross-fix calculator

6) Review of the mechanical package of the receiver and the control/display unit for the purpose of marine installations.

7) Identification and requisition for purchase of long lead items required for the construction of a complete evaluation model (prototype) for the marine navigation range. This task to be fitted in as soon as possible near the beginning, consistent with status of information on the parts required.

Design Review and Implementation of Improvements

1) Examination of test results on the ATC prototype with a view to identifying problem areas and to indicating the need for improvements.

2) Development and implementation of design changes decided on at the design review.

Construction of Evaluation Model

This part of the project comprises building a set of the basic part developed for the ATC which are common to the two projects, integration with the new parts developed for the marine band and evaluation of the complete new DF system. The principal tasks are therefore:

1) Revision of drawings and specifications of the applicable equipment.

2) Release for production of parts and modules etc. of the ATC system as applicable to the marine configuration.

3) Testing and refurbishing of prototype units and modules developed under this project.

4) System integration of the Doppler DF equipment for marine navigation

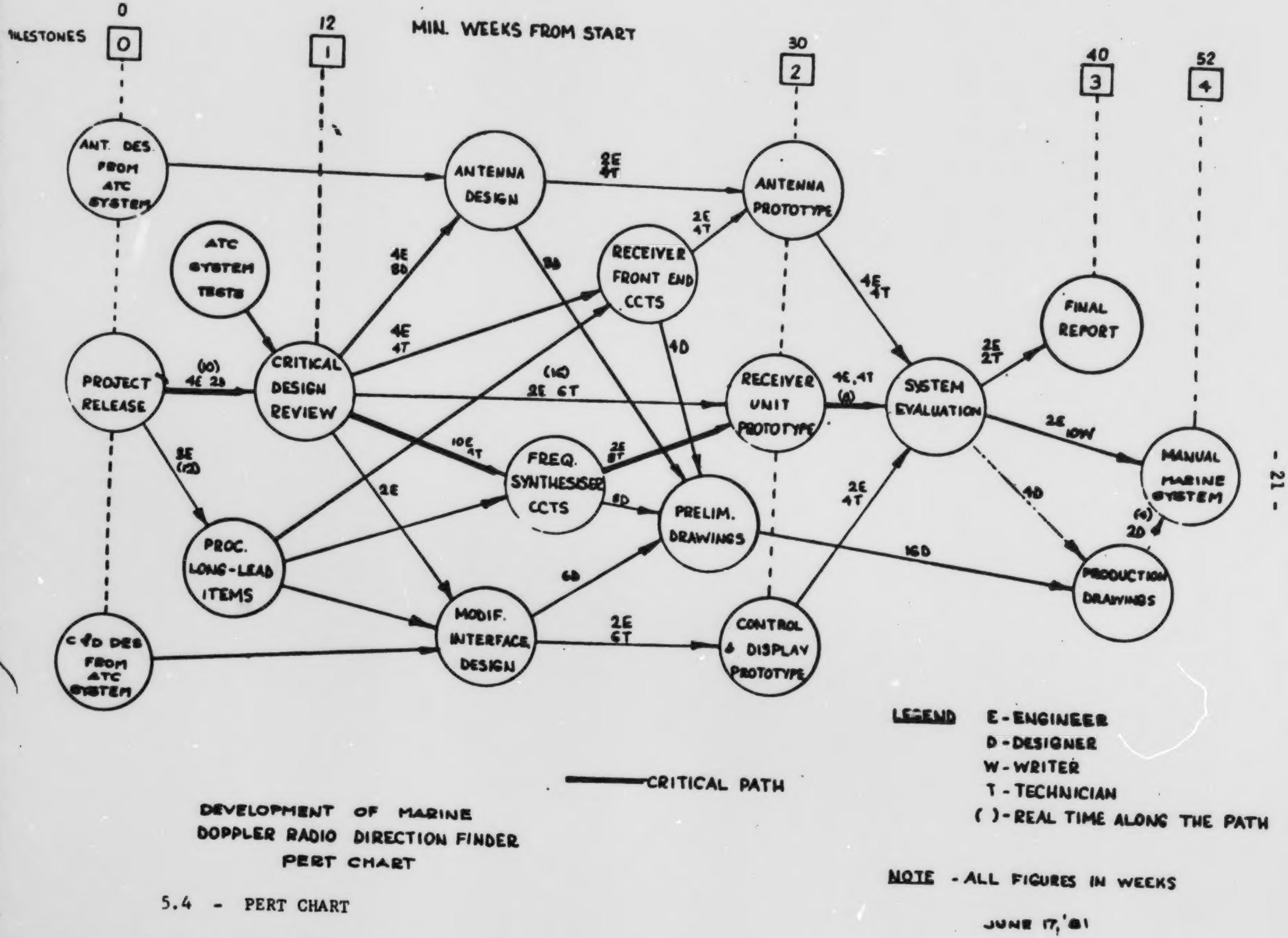
5) Evaluation of the new system

6) Technical Report

7) Documentation update - preparation of manuals

5.3 Special Problems

The attached PERT Chart (Fig. 1) shows the sequential scheduling of the project tasks. This has been built on the assumption of availability of two Development Engineers and one Mechanical Designer. The chart shows the engineering effort involved in man-weeks of the appropriate grade. Real elapsed time is indicated in brackets whenever different from the manweeks shown on each path. A critical path is sketched in red providing a basis for the milestone target dates.


MILESTONES
0
0
12
1
MIN. WEEKS FROM START
30
2
40
3
52
4
ANT. DES. FROM ATC SYSTEM
ATC SYSTEM TESTS
PROJECT RELEASE
C & D DES FROM ATC SYSTEM
CRITICAL DESIGN REVIEW
PROC. LONG-LEAD ITEMS
ANTENNA DESIGN
MODIF. INTERFACE DESIGN
RECEIVER FRONT END CCTS
FREQ. SYNTHESISER CCTS
PRELIM. DRAWINGS
ANTENNA PROTOTYPE
RECEIVER UNIT PROTOTYPE
CONTROL & DISPLAY PROTOTYPE
SYSTEM EVALUATION
FINAL REPORT
MANUAL MARINE SYSTEM
PRODUCTION DRAWINGS
(10) 4E 2D
3E (12)
4E 8D
4E 4T
(16) 2E 6T
10E 4T
2E
2E 4T
8D
2E 4T
4D
2E 8T
8D
6D
2E 6T
4E 4T
4E, 4T (6)
2E 4T
2E 2T
2E 10W
4D
16D
(4) 2D
CRITICAL PATH
DEVELOPMENT OF MARINE
DOPPLER RADIO DIRECTION FINDER
PERT CHART
LEGEND
E - ENGINEER
D - DESIGNER
W - WRITER
T - TECHNICIAN
( ) - REAL TIME ALONG THE PATH
NOTE - ALL FIGURES IN WEEKS
JUNE 17, '81

5.4 - PERT CHART

5.5 R and D Task Estimates

The following estimates are based on the enclosed PERT Chart drawing dated June 17, 1981.

Estimates of manhours required for each task path of the PERT cost are indicated alongside the respective paths, quoting the respective categories: Engineer, Mechanical Designer, Technician, Draftsperson and Technical Writer

The time scale refers to consecutive weeks from the start of project on the assumption that work can be released in the next few weeks. The latest release date for the construction of the complete evaluation prototype for which the estimate is valid is July 30, 1981, after which the continuity of employment will be lost with consequent escalation in costs.

A summary of the manpower involvement in this project by categories is presented below:

Category	Rate $ Per Week	Net Man-weeks Part A	Net Man-weeks Part B	Labour Cost $ Part A	Labour Cost $ Part B	Labour Cost $ Total
System Engineer	750	10	2	7,500	1,500	9,000
Engineer I	600	18	4	10,800	2,400	13,200
Engineer II	420	12	4	5,040	1,680	6,720
Mech. Designer	620	14	2	8,680	1,240	9,920
Draftsperson I	380	16	2	6,080	760	6,840
Draftsperson II	250	16	4	4,000	1,000	5,000
Technician I	440	6	18	2,640	7,920	10,560
Technician II	380	4	20	1,520	7,600	9,120
Tech. Writer	420	4	6	1,680	2,520	4,200
TOTAL LABOUR:				47,940	26,620	74,560
OVERHEAD AT 97%				46,502	25,821	72,323
TOTAL R and D DEPT. LABOUR AND OVERHEAD				94,442	52,441	146,883

5.6 Prototype Development Cost Estimate

This estimate applies to the cost of the additional development program, defined as development of the marine Doppler Radio Direction Finder. It includes the cost of a complete engineering prototype to be delivered to the Dept. of Transport for evaluation purposes.

5.7 Overall Development Cost Estimate

	New Development	Complete Prototype	Total
- to develop additional circuits and design the equipment specific to the marine frequency range of the Doppler RDF System as per this Proposal	94,442		
- to construct, trouble-shoot, evaluate, field-test and refurbish one complete engineering prototype DF System (L + O/H)		52,441	
- workshop labour and outside services		14,200	
- material for one prototype	5,500	30,200	
- plus material handling at 8.5%	382	2,567	
	99,324	99,408	198,732
Plus G and A at 8.5%	8,442	8,450	16,893
	107,767	107,858	215,625
Plus fee at 7.5%	8,082	8,089	16,171
	115,849	115,947	231,796
Direct expenses (field trials, travel, etc.)		4,500	4,500
Plus Administration 2%		90	90
TOTAL:	115,849	120,537	236,386

5.8 Combined Program Economy

By employing the same project team and developing the two systems, ATC and Marine, one after the other and without interruption on a basis of a common modular concept it is possible to keep the overall R and D effort to a minimum. Thus, the additional development (L and O/H) cost required in the marine project is only 99,000/185,000 x 100 or 55% of that projected for the development of the first complete DF System for ATC.

5.9 Milestone Targets

	Target	Week	Estimated Cost To Date
1	To define the specific requirements of the DF System for marine navigation and to design the system in detail sufficient to specify interface data for individual units or modules. To delineate additional R and D pertaining to this marine application. To develop circuits and design packaging necessary to demonstrate the feasibility of the marine range system. To prepare a limited list of long lead items for a complete marine system and to place orders in anticipation of the release of order. To obtain release of order for the construction of a complete marine evaluation model (prototype).		
2	Specifically, to develop antenna, r.f. front end and frequency synthesizer to adapt the system to the marine frequency range. To implement design changes in the Control/Display interface in accordance with the requirements of the Coast Guard Statement of Work dated November 24, 1978. To construct a working prototype of the marine band system.	30	$170,000

	Target	Week	Estimated Cost To Date
3	To troubleshoot and to test the prototype of the system units and to carry out the necessary modifications to achieve the specification targets. To carry out system test on the overall DF System, including electrical performance, temperature and humidity and field trials. To modify the equipment and to continue updating documentation as required to achieve acceptable performance.	40	$220,000
4	To prepare final reports on the project including equipment and system test results. To prepare a draft manual including descriptions of circuits and operating procedures. To prepare final engineering drawings for the project. To refurbish the prototype incorporating corrections introduced in milestone 3. To assist in installing the prototype equipment at the customer's test site for final evaluation.	52	$236,386

5.10 Cumulative Cost Chart

Cash flow estimates have been forecast with the aid of the PERT Chart on a month-by-month basis and the results are shown on the Cumulative Cost Graph below:

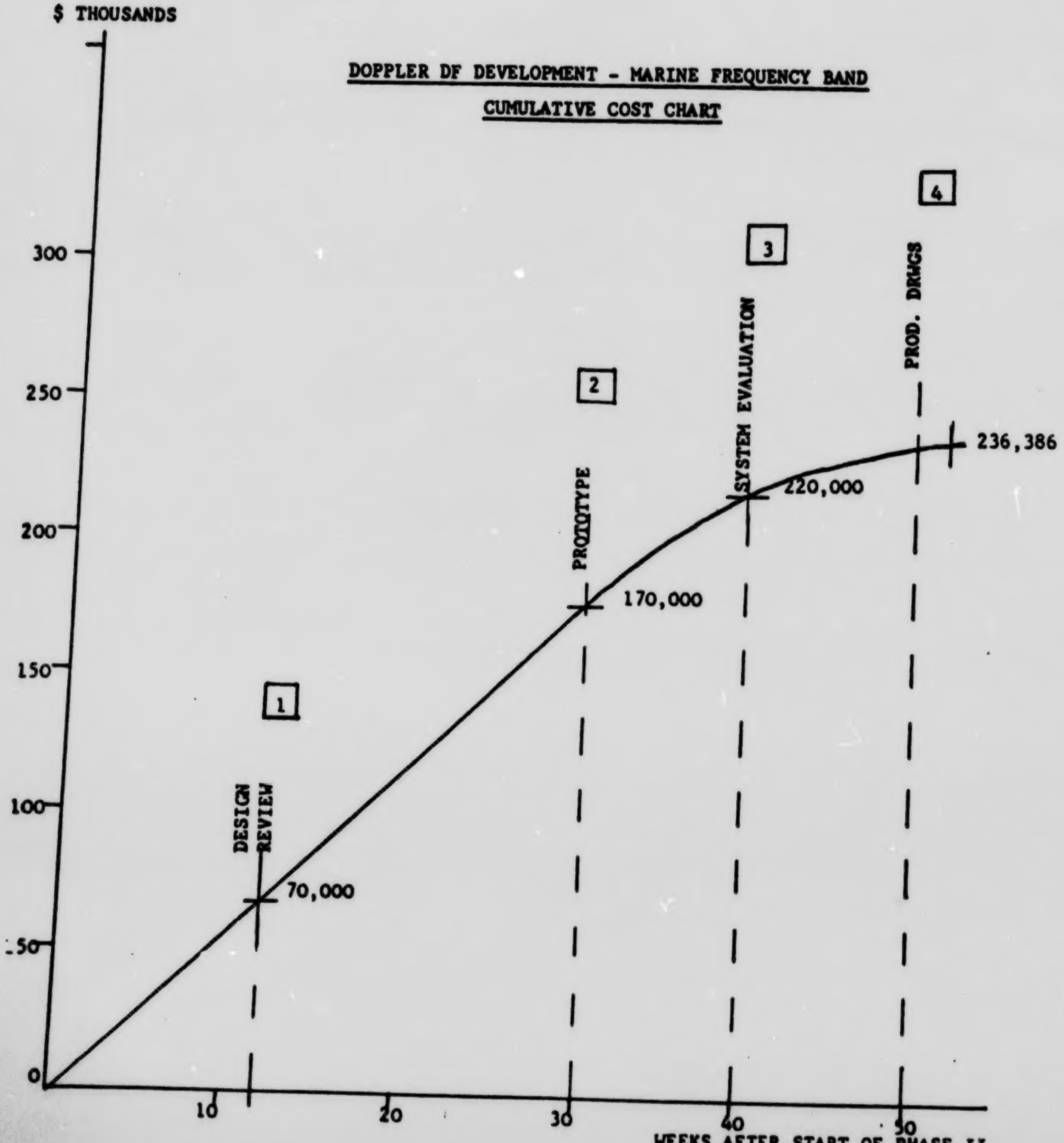


FIG 3

In this forecast, it is assumed that the initial 3 months (Part A) will be limited to R and D labour plus overhead at $20,000 max. per month.

From the release of the construction order on, the effort will be increased to complete the project on the target date.

5.11 Project Team

It is the intention to allow the project team of the ATC development to carry on with the work on the marine version so that their experience can be utilized to the best effect. Hence, the timing limitations on the uninterrupted run of the two projects.

Both projects will remain under the supervision of the same System Engineer.

5.12 Note on the Basis of Costing

Timing is of essence on this project and every effort must be made to avoid delays in the continuation of work. It is with this in mind that the Company has prepared this proposal on the same terms and conditions of costing as the original proposal for ATC. The actual costs are expected to be somewhat higher due to escalation of the overhead rate which, for the R and D, is now approaching 120%.

6.0 MARKETING PROSPECTS

6.1 Domestic Sales

The intention of this program is to have a Canadian designed, and made in Canada, Doppler DF System which can be offered to Transport Canada for land-based marine DF stations.

Domestic requirements, counting new installations and replacement of old systems, are estimated at some 25 equipments spread over the next five years.

6.2 Competition

Competition comes largely from two companies with some tradition in this field:

1) Servo Corporation of America

2) Rhode and Schwarz

Rhode and Schwarz have come up recently with a high accuracy Doppler DF System for marine applications using a 32 element antenna.

None of these firms can offer Canadian manufacturing facilities, and their equipments are based on certain compromise solutions of problems which we expect to overcome in our new design.

6.3 World Market

Our parent company, the AEG-Telefunken, has a Radio DF Department in Ulm (West Germany) which has undertaken to market our Doppler DF equipment through their world-wide sales organization. With our technical advantages and their assistance, we expect to capture 10% to 15% of the world market.

7.0 PATENTS RELATED TO DOPPLER DF PROPOSAL

The following list describes Patents existing, applied for, or in preparation which may conceivably be utilized in the subject of this proposal. This list is complete at this point in time, but other items may be added in due course. The decision to apply any one of these will be exercised at the Design Review stage, at the earliest, but no later than the Prototype stage. In any event, the Design Authority will be duly advised. All the Company Patents, if used, are subject to 5% licensing fee.

Channel Commutation to Eliminate Mismatch Errors in a 2-Channel Receiver

Telefunken Patent Application DAS 1 080 158 (West Germany)
Anordnung zur Seitenbestimmung bei einem Funkpeiler nach dem Zweikanalprinzip
A. Troost - G. Schmucker - 1960

Cancellation of Group Delay Error by Dual Speed Antenna Sampling

New Bayly invention - see para 3.6 (page 6) of Unsolicited Proposal by Z.A. Krajewski, dated June 22, 1978.
- Patent applied for

Computation of Bearing Angle from Sample Data over a Single Cycle of Antenna Rotation by Means of Fourier Analysis

A novel method of data extracting as applied to Doppler DF, which makes the result independent of the group delay of the processing filter.
- Patent description in preparation

Cancellation of Group Delay Error by Reversal of Antenna Rotation

Telefunken Patent Application DT 2613 055 A1 (West Germany)
Anordnung zur Peilung der Einfallsrichtung einer Elektromagnetischen Welle
H.H. Meinke at al. 1976

Antenna Protection against Lightning Damage

Telefunken Patent Application P 25 50 915.3 (West Germany)
Shaltungsanordnung fur Antennen zum Schutzgegen Schaden durch Blitzeinschlag - G. Bodeman, 1975

BAYLY
ENGINEERING
LIMITED

VHF QUASI-DOPPLER MARINE DF SYSTEM

PROPOSAL FOR DESIGN IMPROVEMENTS

1.0 SCOPE

This proposal is a listing of design changes and modifications to be incorporated in the Marine DF system under development in order to improve its performance and reliability, and to reduce the cost of the equipment. The proposed changes are taken with reference to the description of the system as enclosed in the original development contract. They are based on the results of the extensive research carried out, by the Company, over the period of January to July 1982 on the prototype built for the ATC. A systematic breakdown of the recommendations is presented under sub-system headings, assuming that the reader is familiar with the general system concept.

2.0 ANTENNA ARRAY

2.1 Reduce stray pick-ups and reflection irregularities by carrying dipole cables inside the mast tube.

2.2 Provide test injection cables with double shielding with down lead in a separate common shield outside the mast tube. Shunt the test injection monopoles to provide correct termination for the cables. Position test injection monopoles below the ground plane to reduce coupling to omni-antenna.

2.3 Provide omni-antenna cable with double shielding with a separate down lead outside the mast tube. Position the omni-antenna in a central location above the ground plane.

3.0 ANTENNA UNIT ASSEMBLY

3.1 Improve RFI shielding of all the VHF modules (RF front end, LO1 amplifier and Test Injection generator). Include RFI filters to cover input and i.f. bands.

3.2 Add a band pass filter to the LO's amplifier module to clean up the harmonic spectrum of the frequency synthesizer. Increase the level of the final stage by 3 dB, to improve the gain of 1st conversion stages.

3.3 Add filtering to the test injection generator module, in order to clean up the output spectrum. Provide additional amplification, where required.

3.4 Investigate cost effectiveness of using PIN diodes of lower forward resistance in the antenna commutator, in order to reduce losses.

4.0 DF RECEIVER

4.1 The DF receiver is a critical item of design, where phase balance has to be maintained to better than ±10 degrees between the two channels, for all conditions of frequency, signal level and temperature. Experience with the ATC receiver results in the recommendation for complete re-packaging of five different modules, with incorporation of the following details:

4.2 Replace the front-end amplifier with a lower cost item of equivalent NF, but higher inverse isolation and lower forward gain.

4.3 Re-distribute gain between the 2nd and 3rd IF stages for better S/N ratio at low input levels.

4.4 Incorporate stepped AGC in 3 stages: RF, 2nd IF and 3rd IF, distributed so as to avoid intermodulation distortion on strong signals.

4.5 Improve isolation of oscillator buffers to reduce inter-channel cross-talk.

4.6 Improve stability of the AFC with low level inputs.

4.7 Improve linearity of the phase detector by replacing the integration amplifier with a linear push-pull IC.

4.8 Improve signal to noise ratio at the phase detector input, by reducing the final filter bandwidth to 7.5 kHz (Note: the AGC and AFC inputs must remain at 15 kHz bandwidth). This will be feasible with a reduced scan rate and a new program for the bearing processor (see also Bearing Processor).

4.9 Provide external test points and common link switches for quick maintenance check of the phase matching. Provide fine phase match adjustment on the front panel of the receiver unit.

5.0 BEARING PROCESSOR

5.1 The purpose of the bearing processor is to periodically sample the phase of the DF receiver output, and to carry out a Fourier analysis to determine the positive zero crossing of the fundamental component of the scan frequency. The resultant reading gives an indication of the angle of arrival of the incoming wave. This simple process is made more complicated by a number of interfering factors:

i) harmonic ripple of the antenna patterns due to reflections

ii) presence of random noise or impulsive interference (phase jitter)

iii) tolerance of the phase balance of the DF receiver channels

The overall effect is a time variable scatter, often exceeding the limits of linearity of the phase detector with a consequent reduction of accuracy.

5.2 In the ATC prototype (as presented in August 1982), the bearing processor handles this task in 3 stages:

i) a full cycle is coarsely sampled and the phase detection is shifted for those portions of the scan which require extension of the range.

ii) the following, correct, reading samples are processed by Fourier analysis.

iii) the obtained series of bearing readings is further manipulated by time integration, bearing/heading switch, signal overhead, North correction and the extraction of the 'data valid' constant.

Items i) and iii) are performed by separate microprocessors and item ii) is done by pre-programmed hardware of integrated circuits.

5.3 The above configuration is bulky and expensive, and does not lend itself to further improvements or provide flexibility for future new applications. When the design was first made, it was the only way to achieve the required speed of computation. Rapid progress in microprocessors has made it possible today to plan the entire operation for a single program with the great simplification of using a single microprocessor.

5.4 The proposal is to replace five cards of the present sub-system with three new ones and to develop the necessary software to perform all the functions present in the ATC system, plus a number of additional desirable features which will be made possible by the arrangement.

5.5 The possible advantages of the new development can include:

i) reduction in bulk and cost

ii) improvement in reliability, due to fewer components

iii) more accurate setting of the 'course' scan sample by exclusion of the 'wild' spot readings

iv) improvement in the time integration by computing a running average.

v) automatic selection of the integration constant

vi) stabilization of the 'data valid' signal

vii) more reliable storage of the bearing after the signal is turned off

viii) automatic correction of the site errors

ix) readout of target elevation

5.6 In addition, the DF performance in noisy environment will be improved by reducing the scan period and correspondingly lengthening the pulse sampling window. A gain insensitivity of approximately 6 dB may be expected if this feature is combined with the reduction in output bandwidth (see DF Receiver, para 4.8). This approach has the further advantage of reducing errors due to the variation of the receiver group delay.

6.0 AUDIO RECEIVER

6.1 The audio receiver in the ATC prototype has been designed on the same frequency plan as the DF channels, except that the 3rd frequency conversion has been omitted. Experience has shown that the 2nd IF filters (crystal type) became bulky and difficult to procure. It is proposed to re-design this receiver using a different frequency plan and more conventional components available from the portable FM radio industry. A complete re-package of the module is necessary.

7.0 EMERGENCY RECEIVER

7.1 The same argument applies to the emergency receiver channel. Bulk and cost can be saved by using standard circuits and components for what is, in effect, a single frequency monitoring channel.

7.2 However, one additional item will be required for the emergency channel - a sharp pass band (crystal) 1st IF filter to avoid cross-talk from interference from air traffic on adjacent channels.

Z.A. KRAJEWSKI

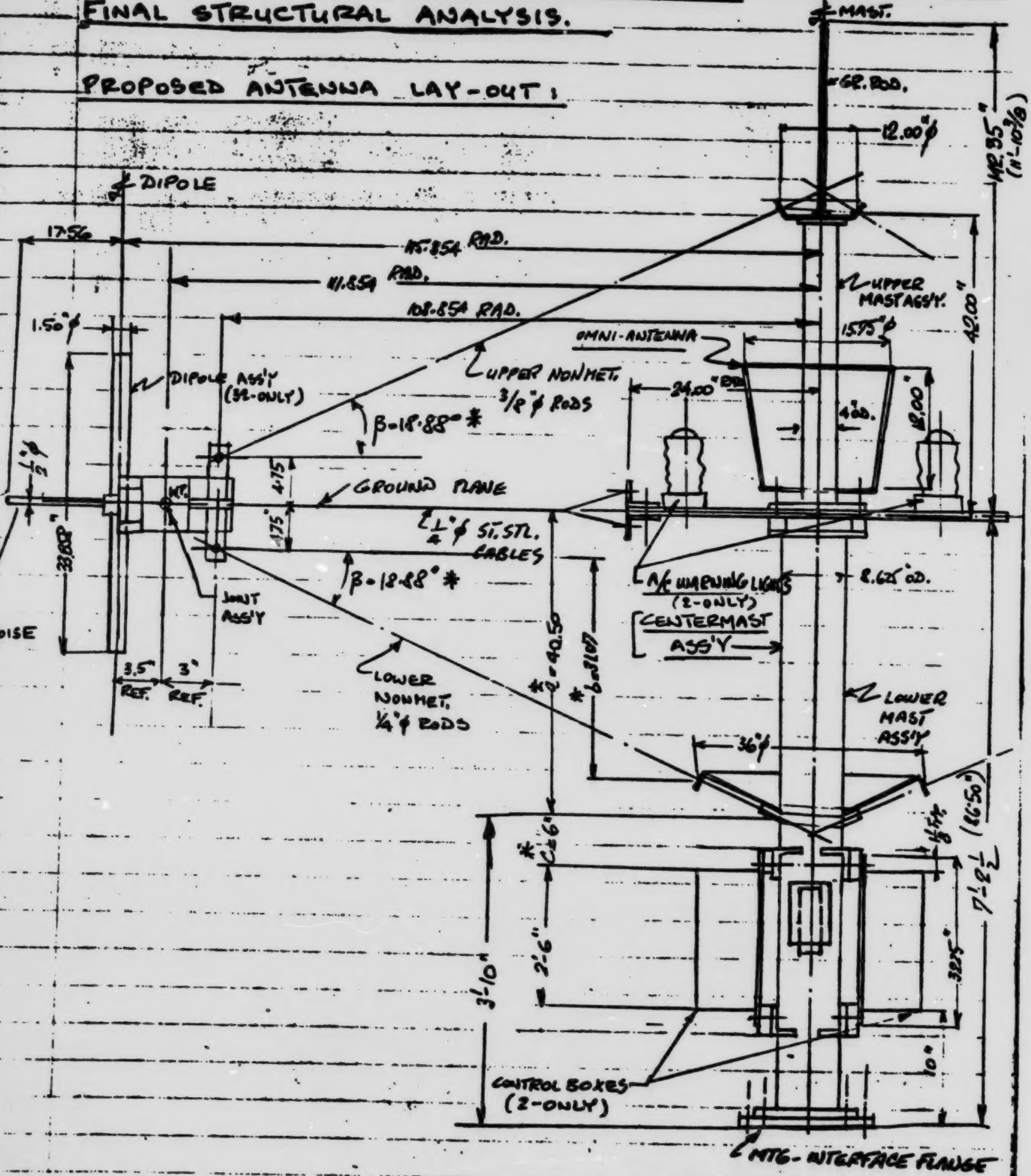
APPENDIX 4

ANTENNA DRAWINGS AND STRUCTURAL ANALYSIS

BY: G. SCHMIDEG
DATE: JUN 24/82
SH. #1 OF 70

32 DP. MARINE DOPPLER ANTENNA SYSTEM
FINAL STRUCTURAL ANALYSIS.

PROPOSED ANTENNA LAY-OUT:



℄ MAST.
5/8 ROD.
12.00"φ
142.35" (11'-10 3/8)
℄ DIPOLE
17.56
115.854 RAD.
111.854 RAD.
108.854 RAD.
UPPER MAST ASS'Y.
40.00"
1.50"φ
15.75"φ
OMNI-ANTENNA
DIPOLE ASS'Y (32-ONLY)
UPPER NONMET. 3/8"φ RODS
β=18.88° *
24.00" BC
4.00.
18.00"
4.75
4.75
GROUND PLANE
1/4"φ ST. STL. CABLES
33.00"
1"φ
β=18.88° *
JOINT ASS'Y
A/C WARNING LIGHTS (2-ONLY)
8.625" OD.
CENTERMAST ASS'Y
C'POISE
3.5" REF.
3" REF.
LOWER NONMET. 1/4"φ RODS
*2-40.50
*6.8107
LOWER MAST ASS'Y
36"φ
(86.50")
1'-6"
*
5 5/8"
7'-2 1/2"
2'-6"
3'-10"
32.5"
10"
CONTROL BOXES (2-ONLY)
MTG. INTERFACE FLANGE

FIG #1

NOTE: FOR DIMENSIONS MARKED WITH ASTERISKS SEE NOTE ON SH #1/A

NOTE 1 FIGURE #1 SHOWS PRELIMINARY DIMENSIONS USED FOR STATIC DATA TAKE OF, SUCH AS DEADWEIGHT, WIND AND ICE LOADS. FINAL CONFIGURATION IS SLIGHTLY CHANGED, WITHOUT EFFECTING IN ANY APPRECIABLE WAY THE STATIC LOAD DATA.

FOR STRESS ANALYSIS, FROM SH#33, FIG#7 FINAL DATA HAS BEEN USED.

FINAL DATA	PRELIMINARY DATA
$\beta_1 = 19.908°$	$\beta = 18.88°$
$a_1 = 42.43''$	$a = 40.50''$
$b_1 = 32.90''$	$b = 31.07''$
$c_1 = 4.07''$	$c = 6.00''$

1.0 ENVIROMENTAL CONDITIONS, BASIC DESIGN.

BASED ON CSA S37-1976
ANTENNA CENTER BETWEEN 40 TO 60 FT. ABOVE GROUND
HEIGHT FACTOR, $C_e = 1.1$
WIND LOAD, ZONE "C" @ $q = 18$ psf
ICE LOAD, CLASS IV @ 2" RAD ICE
ICE WEIGHT @ 56 Lbs/ft^3

1.1 ENVIRONMENTAL CONDITIONS — @ LOWER ICE LOAD.

AT ICE LOAD, CLASS II (1" RAD. ICE) WITH ALL OTHER CONDITIONS THE SAME AS PARA 1.0, CALCULATE CHANGES IN TOWER INTERFACE LOADING CONDITIONS.

2.0 ANTENNA - STRUCTURAL ANALYSIS

ESTABLISHING OVERALL LOADS ACTING ON ANTENNA.

2.1 WEIGHT ANALYSIS - WITH ASSUMED MEMBER SIZES.

CONDITIONS : DRY - NO ICE

- $\frac{1}{2}$ OF SUSPENSION WEIGHT REDUCED TO ANNULAR RING ASS'Y.
- $\frac{1}{2}$ OF SUSPENSION WEIGHT REDUCED TO TOWER MAST ASS'Y.

2.1.1 WEIGHT OF ANNULAR RING ASS'Y, INCLUDING $\frac{1}{2}$ × WEIGHT OF SUSPENSION SYSTEM ;

A.) DIPOLE JOINT SUBASS'Y

JOINT - AL. CASTING	3.0#
REAR STRUT	1.07#
CLAMP #1 (2-REQ'D)	.183#
CLAMP #2 (1-REQ'D)	.15#
C'POISE ASS'Y	.318#
SHORT DIPOLE ASS'Y	2.564#
BOLTS + H'WARE	.5# (LOT)
RF CONN. + SUPPORT BRIDGE	.7#

8.485#/JOINT × 32 = 271.52#

PARA 2.1.1 CONT'D.

b.) UPPER NONMETALLIC SUSPENSION SYSTEM (32-ROD SYSTEM)

UPPER STRUT LENGTH = 109.45" FROM PIN TO 12"ϕ DISC ON MAST.

USING $\frac{3}{8}\phi$ EXTRENE RODS WITH REBORED $\frac{1}{4}$ SIZE ST. STL. FITTINGS

WITH EXTRENE ROD UNIT WEIGHT @ .098#/LIN FT.

WEIGHT OF $\frac{1}{2}$ - LENGHT + OUTER FITTINGS ONLY :

$.098 \times 109.45 \times \frac{1}{2} \times \frac{1}{12} = 0.4469^{\#}$

WEIGHT OF OUTS. FITTING = $.30^{\#}$

$.7469^{\#}$ ea × 32 = 23.90#

c.) LOWER NONMETALLIC SUSPENSION SYSTEM (16-ROD SYSTEM)

LOWER STRUT LENGTH FROM PIN TO 36"ϕ INNER SUPPORT

= 96.00" = 8'-0

ROD DIA = .25" @ .044#/lin ft.

USING $\frac{1}{2}$ WEIGHT, INCL. OUTER $\frac{1}{4}$"ϕ FITTING WEIGHT,

$.044 \times 96 \times \frac{1}{2} \times \frac{1}{12} = 0.176^{\#}$ (WEIGHT OF 0.5 × ROD)

OUTER FITTING = $.35^{\#}$

$.526^{\#}$ ea × 16 = 8.416#

d.) NONMETALLIC JOINT INTERCONNECTING SQ. TUBING ASS'Y.

THIS SYSTEM INCLUDES : OVERALL STRUT LENGTH = 18.55" ea, INCL FLANGE

NONMET. SQ. TUBING, 3×3" SQ. OUTS., $\frac{1}{4}$" WALL, WEIGHT 2.01#/ft

LENGTH = 18.55 − 2 × .25 ≈ 18.0"

$$\text{WEIGHT} = \frac{18}{12} \times 2.01 = 3.015^{\#} \times 32 = 96.48^{\#}$$

AL. FLANGE { FLANGE : $4 \times 4 \times \frac{1}{4} \times .10 \times 2 = 0.8^{\#}$

STEM : $(2.5^2 - 2.125^2) .1 \times 2.5 = \underline{0.433^{\#}}$

$1.2335^{\#}$/FLANGE × 64 = 78.94#

HARDWARE, ST. STL. 1-ONLY $\frac{1}{4}\phi \times 1$" LG HEX. HD. BOLTS

" $\frac{1}{4}$-20UNC NUTS

" $\frac{1}{4}$-SIZE L.WAS

2-ONLY $\frac{1}{4}\phi \times \frac{1}{2}$" LG PINS } .16# × 64 = 10.24#

= 185.66#

PARA 2.1.1 CONT'D.

e_1 "REDUCED" WEIGHT, GROUND PLANE - SUSPENSION SYSTEM INCLUDING ST. STL. CABLES WITH FITTINGS, 4-ONLY TEST ANTENNAS AND COAX CABLE SYSTEM.

ST. STL. CABLES @ SINGLE CABLE LENGTH = 90.567"

WEIGHT OF $\frac{1}{8}\phi$ ST. STL. CABLE, 29#/1000 FT

$\frac{90.567}{2} \times 29 \times \frac{1}{12000} = 0.1094$#/½ CABLE LENGTH × 64 = 7.00#

OUTER $\frac{1}{8}$ SIZE CABLE FITTINGS 2-ONLY @ .22#/fitting × 64 = 14.08#

COAX CABLE WEIGHT, JACKETED $\frac{3}{8}$" NOM. SIZE
@ .12#/lin ft (OD = .435" ϕ OVER JACKET)

OVERALL LENGTH OF COAX CABLE = 111.85

WEIGHT (REDUCED) = $\frac{1}{2} \times 111.85 \times \frac{.12}{12} = .56$#/CABLE × 32 = 17.89#

COAX CONN ASS (½ ONLY) = 0.2# × 32 = 6.4#

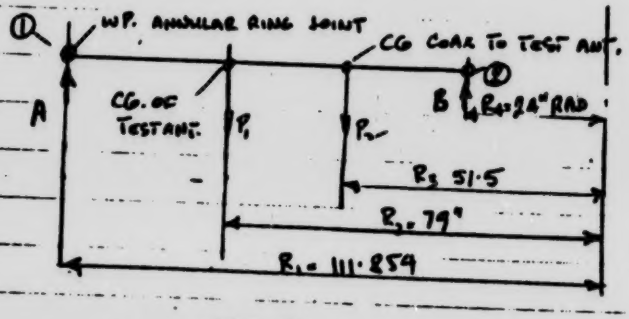


FIG. #2

WEIGHT DISTR. COAX ANT. + TEST ANT.

MOMENT TO "A"

$$P_1(R_1 - R_2) \pm P_2\,i(R_1 - R_3) - B(R_1 - R_4) = 0$$

WHERE $P_1 = 0.9$# (EA TEST ANT.) × 4 = 3.2#

$P_2 = (85-24) \times \frac{.12}{12} \times .85 \times 4 = 2.074$#

AND $R_1 - R_2 = 32.854$"

$R_1 - R_3 = 60.354$"

$R_1 - R_4 = 87.854$"

THUS $B = \frac{3.2 \times 32.854 + 2.074 \times 60.354}{87.854} = 2.62$#

$A = P_1 + P_2 - B = 3.2 + 2.074 - 2.62 = \longrightarrow 2.65$#

Red. comp. weight [illegible]

PARA 9.1.1 CONT'D.

e., CONT'D.

Σ REDUCED WEIGHT = 7.00
14.08
17.89
6.4
2.65
48.02# → 48.02#

TOTAL REDUCED WEIGHT - OVERALL ANNULAR RING ASS'Y. (DRY)

a = 271.52#
b = 23.90#
c = 8.416#
d = 185.66#
e = 48.02#
537.516# = TOTAL DRY WEIGHT - ANNULAR RING + "REDUCED" SUSPENSION

NOTE: ABOVE "DRY" WEIGHT OF ANNULAR RING ASS'Y IS BASED ON FOLLOWING CRITERIAS:

aa., UPPER SUSPENSION RODS - 3/8"ϕ NONMETALLIC TYPE, QUANTITY: 32-REQ'D
bb., LOWER " " - 1/4"ϕ " " , QUANTITY: 16-REQ'D
cc., JOINT INTERCONNECT SQ. TUBE ASS'Y WITH INDIVIDUAL FLANGES @ BOTH ENDS BOLTED + PINNED TO JOINT CASTINGS - SQ. TUBE 3" SQ. OUTS.
2.5" SQ. INS.
d.d., 50% OF NONMETALLIC SUSP. SYSTEM WEIGHT IS ASSIGNED TO ANNULAR RING ASS'Y. ("REDUCED" WEIGHT) 100% OF WEIGHT OF EXTERIOR FITTINGS ASSIGNED TO ANNULAR RING ASS'Y.
ee., GROUND PLANE CABLES, FITTINGS + COAXIAL LINES, CONNECTORS, SPECIAL ANTENNAS - REDUCED WEIGHTS ASSIGNED TO ANNULAR RING ASS'Y IS BASED ON LOCATION OF CG OF INDIVIDUAL ITEMS RELATIVE TO SUPPORT POINTS. (REDUCTION)

PARA 2.1.2 SUSPENSION SYSTEM - OUTSTANDING WEIGHT, TO BE ASSIGNED TO CENTERMAST ASS'Y.

a.a.) UPPER SUSPENSION RODS $\frac{3}{8}$ϕ .4469 # ea.
INNER FITTINGS + SPRING SUSP. .4 # ea
.847 # ea × 32 = 27.10 #

b.b.) LOWER SUSPENSION RODS $\frac{1}{4}$" ϕ .176 # ea
INNER FITTINGS + SPRING SUSP. .3 # ea
.476 # ea × 16 = 7.6 #

C.C GROUND PLANE, ST. STL. CABLES + FITTINGS + COAX. CABLES AND
SPECIAL ANTENNAS 7.00 #
FITTINGS WITH SPRING SUSP. 14.08 #
COAX CABLES 17.89 #
SPEC. ANT. + ITS COAX CABLES 2.62 #
41.594 # ⟶ 41.594

Σ = 76.294 #

PARA 2.1.3 DRY WEIGHT - CENTERMAST ASSEMBLY.

LIGHTNING ARRESTOR ROD
$\frac{3}{4}$ϕ × 105.35" LG @ 1.405 #/ft ≅ 15 #
+ CABLE, FITTING, CLAMP, ETC = 3 #
UPPER 1st FLANGE, SPRING SUPPORT = 4.4 #
FITTINGS, HARW. = 3 #
UPPER 2nd SUPP. FLANGE
10"ϕ × $\frac{1}{4}$" TH = 1.96 #
UPPER MAST, PIPE, 4" N. DIA
AL. PIPE, 4.5 OD/4.026 ID @ 3.733 #/ft = 13.07 #
UPPER MAST - LOWER FLANGE
10" DIA × $\frac{3}{8}$" TH = 7.85 #
GR. PLANE MEMBRANE
80% of 42" DIA × $\frac{1}{4}$" TH = = 36 #
EXT. ANGLES - 2 × 2 × $\frac{1}{4}$ @ 1.115 #/ft × $\frac{146.96"}{12}$ = 29.31
RAD. RIBS, $1\frac{1}{2}$ × 2 × $\frac{1}{4}$ L @ .974 #/ft × $\frac{19.4"}{12}$ × 8 = 19.6 #
LOWER INNER FLANGE
10" DIA × $\frac{3}{8}$" TH = 2.94

} PARTIAL SUM = 128.135 #

PARA 2.1.3 C'MAST ASS'Y - DRY WEIGHT - CONT'D.

PERIMETER CASTINGS = GR. PLANE DISC

AL. 2"LG, $\frac{1}{2}$"TH × 1"W @ .1#/in³ = .1#EA × 64 = 6.4# — 6.4#

SPACERS BETW. RAD. RIBS 1" DIA × $\frac{1}{2}$"LG × 5×4 @ .1#/in³ = .78# — .78#

HARDWARE
$\frac{1}{4}$"φ BOLT, 1"LG = .028#
$\frac{1}{4}$"φ NUT = .008#
$\frac{1}{4}$"φ L.W. = .0025#
} ×2×64 for perim fittings = 14.14#

H'WARE - OUTER FL.
$\frac{1}{4}$"φ BOLT, 1"LG
$\frac{1}{4}$"φ NUT
$\frac{1}{4}$" L.W
} .1105# ea/set × 36 = 3.98#

H'WARE - RAD. RIBS
$\frac{1}{4}$"φ BOLT, $1\frac{1}{2}$"LG = .035# ea
$\frac{1}{4}$"φ NUT = .008# ea
$\frac{1}{4}$"φ L.W = .0025 ea
} × 20 = .91#

} GR. PLANE DISC HARDW. = 19.03#

AIRCRAFT WARNING LIGHTS (2-ONLY) — 10.00#

INSULATORS (4-ONLY) — 9.00#

OMNI ANTENNA - $\frac{1}{2}$"N.DIA BRASS TUBE, .5" ea, 12 sq @ .256#/ft
length = $(15.75 \times \pi + 12 \times \pi + 12 \cdot 14 \times 4) \cdot \frac{.256}{12}$ = 2.89#
LEGS - BRASS, 1" × 3" × $\frac{3}{16}$ TH @ .692#/ft × 4 = .692#
SPLIT FITTING, 1" DIA × $1\frac{1}{2}$"LG × 4 @ 2.144#/ft = 1.072#
4.654# → 4.654#

SPACER BETW. LOWER MAST AND GR. PLANE
SEGMENTED DISC - 10" OD - 8.625 ID × $1\frac{1}{2}$" HIGH @ 50% = 1.257#

ST. STL. HARDW. WEIGHT
{ 12 - BOLTS - 3/8"φ × 2½"LG @ .083# ea
12 NUTS 3/8" SIZE .020# ea
12 L.W 3/8 SIZE .009# ea
} .112#/set × 12 = 1.344#

UPPER FLANGE, LOWER MAST, $\frac{3}{8}$"TH, 10" DIA = 2.94#

LOWER MAST, 8"N. DIA PIPE, 84"LG @ 9.839#/ft = 68.873#

FLANGE #1 (LOWER) 12" DIA, $\frac{1}{2}$"TH AL. = 5.65#

FLANGE #2 (LOWER 14" DIA, $\frac{1}{2}$"TH. STL. GALV. = 21.55#

INNER BOLTS, LOWER FLANGE, HEX. HD, $\frac{1}{2}$-13 × 1"LG ST.STL - 8 REQ'D - .144# eq
NUT $\frac{1}{2}$-13NC " - 8 - REQ'D - .044# eq
SPRING L.W " - 8 - REQ'D - .015# eq
} = .203 × 8 = 1.624#

PARTIAL WEIGHT = 153.102#

SH#8 OF 70

PARA 2.1.3 C'MAST ASS'Y - DRY WEIGHT - CONT'D.

ADJUSTING LUG - WITH HARDWARE, LOWER FLANGE (EST.)	3.00#

WEIGHT OF LOWER SUSPENSION SUPPORT - SPINNING

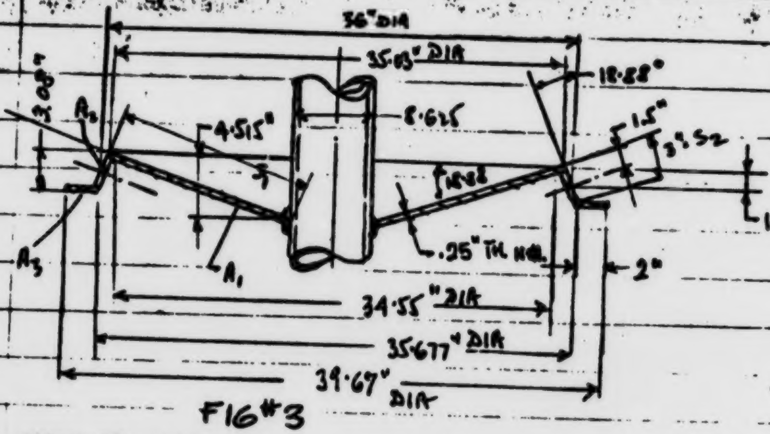


FIG #3

INNER TRUNKATED CONE SURF = A_1 ; WHERE $S_1 = 13.95"$

$$A_1 = \pi S_1 (R_1 + r_1) = \pi \times 13.95 \left(\frac{35.03}{2} + \frac{8.625}{2} \right) = 956.59 \text{ in}^2$$

$$A_2 = \pi S_2 (R_2 + r_2) = \pi \times 3 \times \left(\frac{35.677}{2} + \frac{35.03}{2} \right) = 333.19 \text{ in}^2$$

$$A_3 = \frac{\pi}{4} (D_3^2 - D_2^2) = \frac{\pi}{4} (39.67^2 - 35.677^2) = 236.29 \text{ in}^2$$

$$\Sigma A = 1526.07 \text{ in}^2$$

Volume = $\Sigma A \times .25 = 381.51 \text{ in}^3$

Weight @ 0.1#/in³ = 38.15#

.8# ← LESS SLOTS IN CENTER

37.35# →

	37.35#
WEIGHT - C'BOX - 2-ONLY @ 50# EA	100.00#
C'BOX SUPPORTS, 2 × 2 × 1/4 L ANGLES, 2'-0 LG, 4 REQ'D @ 1.115#/ft	= 8.92#
ACCESS STEP + SUPPORT	
2 × 2 SQ. TUBING, 1/8 WALL 58.75" LG eq × 2 × .983#/ft	= 9.625#
STEPS 4/SIDE, 3/4" ϕ ROD × 12" @ .518#/ft	= 4.144#
END STOPPER WASHERS	= .5#
MTG. HARDWARE C'BOXES	= .5#
RAINGUARDS + REINF. @ COAX CABLE EXITS (2-REQ'D)	= 4#
COAX CABLE RUN - ALONG MAST	= 14#
MISC. CLAMPS, WIRING TO AIRC. W. LIGHT + OMNI-ANT.	= 10#
SUBTOTAL	= 198.039#

PARA 2.1.4 WEIGHT SUMMARY - DRY.

ANNULAR RING ASS'Y, INCL. REDUCED WEIGHT, SUSP. SYST. = 537·516#
BALANCE OF SUSP. SYST. + MISC. REDUCED TO MASS = 76·294#
C'MAST ASS'Y WEIGHT = 127·135#
+ 153·107#
+ 192·039#
TOTAL C'MAST, DRY W. = 548·575# → 548.575#
ANTENNA — TOTAL DRY WEIGHT = 1086·091# ✓

PARA 2.2 WIND LOAD ON ANTENNA ASSEMBLY - DRY - NO ICE

PARA 2.2.1 . DESIGN CONDITIONS - ANTENNA SYSTEM.

DESIGN CONDITIONS: CSA S37-1976 (MODIFIED)

ANTENNA ELEVATION (ABOVE GROUND) 40 TO 60 Ft. HEIGHT FACTOR $C_e = 1.1$

WIND LOAD ZONE "C", WITH $q = 18$ psf @ FLAT PLATE
CORRESPONDING TO 176 KM/H = 109·38 MPH WIND. WITH SHAPE FACTOR = 1.5 (FOR FLAT)
IT CORRESPONDS TO 215·55 KM/H = 139 MPH

DETAILED LOADING CONDITIONS:

DESIGN WIND PRESSURE ON COMPONENTS (RE. STD. pp. 15)

$$p = q\, C_e C_g C_p$$ - [Lbs] STATIC WIND PRESSURE ON STRUCTURE

WHERE

$q = 18.00$ psf FOR FLAT SURFACES
$C_e = 1.1$ (HEIGHT FACTOR OVER 40 - 60 Ft. ABOVE GROUND ELEV.
$C_g = 2.0$ GUST EFFECT FACTOR
$C_p = 1.5$ FOR FLAT SURF. ⎤
1.0 FOR CYLINDR. SURF. ⎥ SHAPE FACTOR
1.2 FOR GUYS ⎦

EFFECT OF LATTICE STRUCTURE - TRANSPARENCY OF "SHADED" MEMBERS USE PROJECTED AREA TO WIND × FACTOR OF 2.0, WHERE APPLICABLE.

GUYS - INITIAL TENSION = 10% OF BREAKING STRENGTH
WITH 15% MAX, 8% MIN ADVISED
BUT CAN BE GREATER IF JUSTIFIED.

PARA 2.2.2 PROJECTED SURFACE AREAS AND WIND LOADS.
(NO ICE CONDITION)

PARA 2.2.3 ANNULAR RING ASS'Y WITH "REDUCED" SUSPENSION SYSTEM.

FOR FLAT USE $p = 18 \times 1.1 \times 2.0 \times 1.5 = 18 \times 3.3 = 59.4$ psf ; FOR ROUND $p = 18 \times 1.1 \times 2 \times 1.0 = 18 \times 2.2 = 39.6$ psf.

FRONTAL PROJECTION – JOINT ASS'Y – WIND LOAD

* FRONT = 4" × 4.5" = 18 in² = [illegible] ft² (flat) @ 59.4 psf = 7.425#

REAR STRUT = $\frac{3}{8} \times (11" - 4) = 2.625$ in² = .018 ft² (flat long bar) @ 59.4 psf = 1.069#

DIPOLE 1.5"ϕ × (33.858 − 4) = 44.787 in² = .311 ft² (Round) @ 39.6 psf = 12.31#

C'POISE 1.5"ϕ FACE → $\frac{1.5^2 \pi}{4}$ = 1.76 in² = .012 ft² (FLAT) @ 59.4 psf = .712#

21.516#

SIDE PROJECTION – JOINT ASS'Y – WIND LOAD

* BODY SIDE EL. (4" × 7") − (3" × 7) = 7 in² = .048 ft² (flat) @ 59.4 psf = 2.887#

* REAR ST. 2 × (11 − 3) = 16 in² = 0.111 ft² (flat) @ 59.4 psf = 6.6#

DIPOLE 1.5 × (33.858 − 3) = 46.28 in² = .32 ft² (Rd) @ 39.6 psf = 12.72#

C'POISE .5" × 16.8 = 8.4 in² = .058 ft² (Rd) @ 39.6 psf = 2.311#

DIPOLE SUPPORTS 3 × 1.5 × 1.75 = 7.87 in² = .054 ft² (FLAT @ 59.4 psf = 3.248#

27.766#

* THUS, IN DRY CONDITION, DUE TO THE SHADOW EFFECT OF A RING, 3" WIDE, WHICH WILL BE CONSIDERED IN ADDITION, THE WIND LOAD VARIATIONS BETWEEN DIPOLES WITH 0° TO 90° AZIMUTH TO WIND DIRECTION CHANGES FROM 21.52# to 27.77# OR 22.5% MAX. OR ± 11.25% FROM MEDIAN. ASSUMING "AVERAGE" WIND LOAD FOR THESE JOINTS

$$\frac{27.766 + 21.516}{2} = 24.64 \text{ \#/joint}$$ WILL BE USED.

WIND LOAD DUE TO DIPOLE ASS'Y – 24.64 #/JOINT × 32 = 788.512#

WIND LOAD DUE TO ANNULAR RING (3" SQ. TUBING)

3 × (111.254 + 1.5) × 2 = 680.124 in² = 4.723 ft² (flat) @ 59.4 psf = 280.55

CONSIDER TRANSP. FACTOR OF 2.00; 280.55 × 2 = 561.102#

REDUCED WIND LOAD – SUSPENSION MEMBERS : USE $p = 18 \times 1.1 \times 2.0 \times 1.2 = 18 \times 2.64 = 47.52$ psf

UPPER RODS, $\frac{1}{2} \times 32 \times (42 - 4.75) \times .375$ = 223.5 in² = 1.55 ft² (ROUND GUY) @ 47.52 psf = 73.79#

LOWER RODS, $\frac{1}{2} \times 16 \times 31.07 \times .25$ = 62.14 in² = .4315 ft² (ROUND GUY) @ 47.52 psf = 20.50#

GR. PL. GUYS, IND. GUY LENGTH – 98.8"

FOR SHADOWING EFF. TAKE 50% ONLY

THUS 0.5 × .5 × .125 × 98.8 × 64 = 197.6 in² = 1.37 ft² (ROUND GUY) @ 47.52 psf = 65.20#

SUBTOTAL = 1509.07#

PARA 2.2.3 CONT'D.

COAX CABLES, REDUCED, ROUND @ 50%

.5 × .5 × .435 × 98.8 × 32 = 343.82 in^2 = 2.38 ft^2 @ 39.6 psf. = 94.55 #

TEST ANTENNAS

6.5 × .25 = 1.625 in^2 = .011 ft^2 flat @ 59.4 psf = 0.65 # eq

CONN = .75 × 2 in = 1.5 in^2 = 0.010 ft^2 rd. @ 39.6 psf = 0.412 # eq

TUBE .5 × 6 in = 3.0 in^2 = 0.02 ft^2 rd @ 39.6 psf = 0.824 # eq

1.887 # eq × 4 = 7.54 #

+ COAX .435 × 75 × 32.62 in^2 = .226 ft^2 rd @ 39.6 psf = 8.97 # eq × 4 = 35.88

43.42 #

ASSIGN 50% TO ANN. RING = 21.71 #

TOTAL WIND LOAD, (DRY) ANNULAR RING ASS'Y

FROM pp. # 10 Σ = 1509.07 #

+ 94.55 #

+ 21.71 #

ΣΣ = 1625.33 # ⟶ 1625.33 #

PARA 2.2.4 WIND LOAD ON C'MAST DUE TO GUY WIND RESISTANCE. (+ TEST ANT. + COAX LINES)

a.) DUE TO UPPER SUSP. SYSTEM	73.754 #	
b.) DUE TO LOWER " "	20.50 #	
c.) DUE TO GROUND PL. GUYS	65.20 #	181.46 #
d.) DUE TO COAX CABLES	94.55 #	
e.) DUE TO TEST ANTENNAS + ITS COAXES	21.71 #	
Σ =	254.00 #	⟶ 254.00 #

PARA 2.2.5 WIND LOAD (DRY) ON C'MAST ASS'Y

ON LIGHTN. ARR. ROD 3/4 DIA × 102" = 76.5 in^2 = .53 ft^2 @ 39.6 psf (round) = 21.04#

ON UPPER DISC 14.83 DIA × 1" HIGH = 19.83 in^2 = .102 ft^2 @ 39.6 psf (") = 4.078#

UPPER FLANGE 10"ϕ × .25 = 2.5 in^2 = 0.017 ft^2 @ 39.6 psf (round) = .687#

UPPERMAST, TUBE 4.5"ϕ × 41" = 184.5 in^2 = 1.28 ft^2 @ 39.6 psf (round) = 50.73#

LOWER FLANGE 10"ϕ × .375 = 3.75 in^2 = 0.026 ft^2 @ 39.6 psf (round) = 1.03#

AIRC. WARN. L. 4.5"ϕ × 10" LG × 2 = 90 in^2 = .625 ft^2 @ 39.6 psf (round) = 24.75#

OMNI ANT. UPPER RING 2 × 15.75 × .5 = 15.75 in^2 = .109 ft^2

LOWER RING 2 × 12 × .5 = 12 in^2 = .083 ft^2

LEGS 4 × 0.5 × 12.14 = 24.28 in^2 = .168 ft^2

.3606 ft^2 @ 39.6 psf = (round) = 14.28#

SUPPORTS $4 \times \frac{3}{16} \times 3$ = .225 in^2 = .0156 ft^2 @ 59.4 psf (flat) = .928#

INSULATORS 4 × 2" × 3 = 24 in^2 = .166 ft^2 @ 39.6 psf (round) = 6.6#

GROUND PLANE, DISC $4\frac{1}{4}$ × 48 = 204 in^2 = 1.4166 ft^2 @ 39.6 psf (round) = 56.1#

SPACERS + LOWER FL. TOP OF LOWER MAST = 10 × $1\frac{7}{8}$ = 18.75 in^2 = .13 ft^2 @ 39.6 psf (round) = 5.15#

LOWER MAST = $8.625 \times (\underbrace{86.5 - 1.875 - 2 - 32.75 - 4.5}_{46"})$ = 396.75 in^2 = 2.755 ft^2 @ 39.6 psf (round) = 109.106#

LOWER SUSP. - SPINING 40 × 4.5 = 180 in^2 = 1.25 ft^2 @ 39.6 psf (round) = 49.5#

C' BOX (FRONT - ONE - ONLY) 24 × 32.25 = 774 in^2 = 5.375 ft^2 @ 59.4 psf (flat) = 319.27#

CLIMBING STRUTS $\begin{cases} 2" \times 40" \times 2 = 160 \text{ in}^2 = 1.111 \text{ ft}^2 \\ 10 \times .75 \times 4 \times 2 = 60 \text{ in}^2 = .416 \text{ ft}^2 \end{cases}$

@ 59.4 psf (flat) = 66.00#

@ 39.6 psf (round) = 16.5#

LOWER MTG FL. #1 12" × 0.5 = 6 in^2 = 0.0416 ft^2 @ 39.6 psf (round) = 1.65#

" " FL #2 14" × 0.5 = 7 in^2 = .0486 ft^2 @ 39.6 psf (round) = 1.925#

HOR. WIND LOAD ON C'MAST — SUBTOTAL = 749.324#

HOR. WIND LOAD ON C'MAST DUE TO GUYS SUBTOTAL = 254.00#

TOTAL WIND LOAD - MAST ASS'Y - DRY = 1003.32#

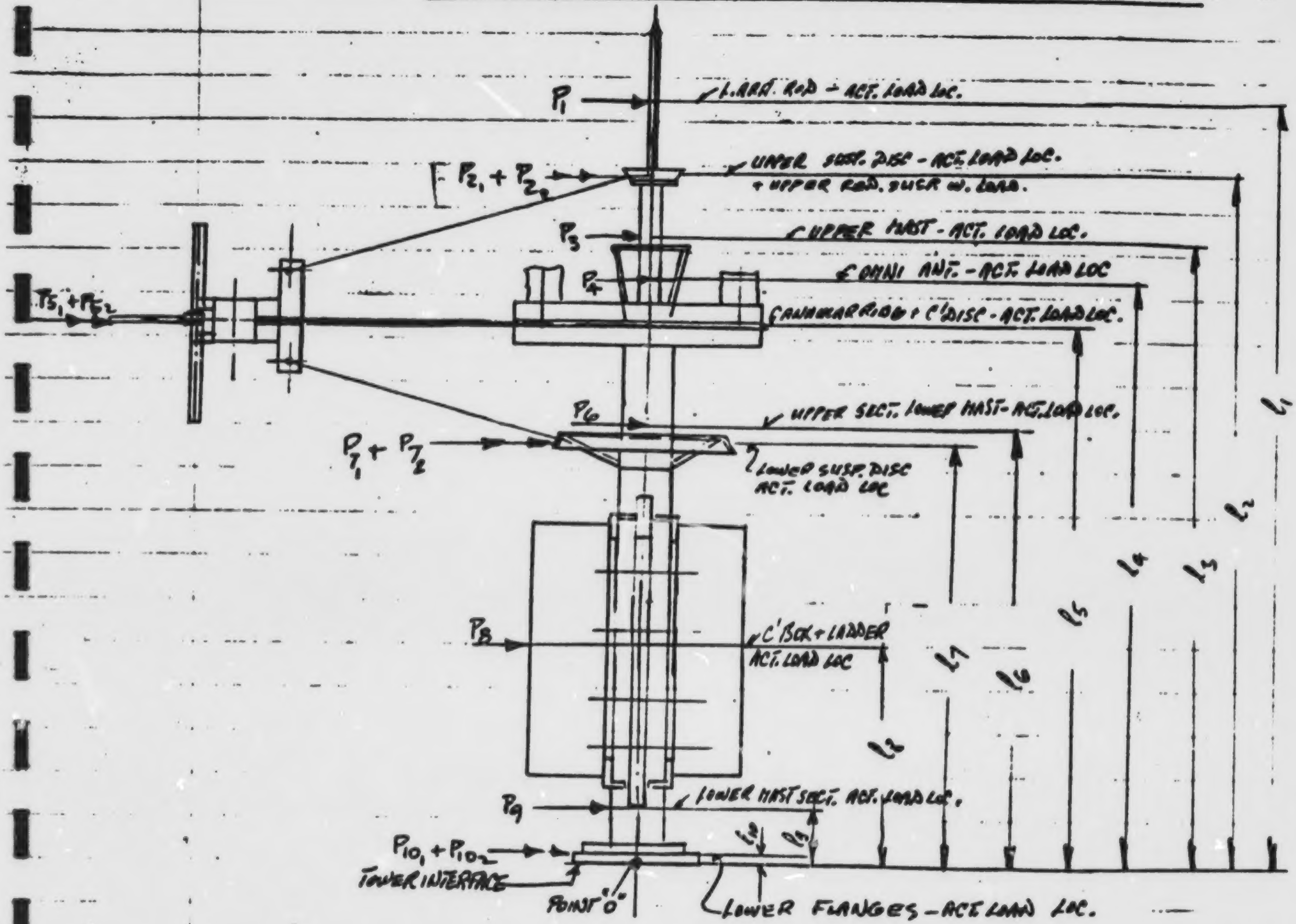
PARA 2.2.6 TOTAL WIND LOAD (DRY) ANTENNA ASS'Y

WINDLOAD ON ANNULAR RING ASS'Y, INCL. SUSPENSION (RED.) = 1625.33#

WINDLOAD ON C'MAST ASS'Y, INCL. SUSPENSION (REDUCED) = 1003.32#

TOTAL HOR. WIND LOAD = 2628.65#

PARA 2.2.7 OVERTURNING MOMENT @ TOWER INTERFACE DUE TO WIND (DRY) ON ANTENNA ASSEMBLY.



P_1
L.ARR. ROD – ACT. LOAD LOC.
$P_{2_1} + P_{2_2}$
UPPER SUSP. DISC – ACT. LOAD LOC.
+ UPPER RAD. SUSP. W. LOAD.
P_3
UPPER MAST – ACT. LOAD LOC.
P_4
OMNI ANT. – ACT. LOAD LOC
$P_{5_1} + P_{5_2}$
ANNULAR RING + C'DISC – ACT. LOAD LOC.
P_6
UPPER SECT. LOWER MAST – ACT. LOAD LOC.
$P_{7_1} + P_{7_2}$
LOWER SUSP. DISC ACT. LOAD LOC
P_8
C'BOX + LADDER ACT. LOAD LOC
P_9
LOWER MAST SECT. ACT. LOAD LOC.
$P_{10_1} + P_{10_2}$
TOWER INTERFACE
POINT "0"
LOWER FLANGES – ACT. LOAD LOC.
l_1
l_2
l_3
l_4
l_5
l_6
l_7
l_8
l_9
l_{10}

LOCATION OF WINDLOAD – CONCENTRATED @ MAST ELEVATION

FIG # 4

OVERTURNING MOMENT ABOUT "0"

WHERE $P_1 = 21.04^{\#}$ ✓ $l_1 = 178.675$ in (LOAD @ L. ARRESTR) ; $M_1 = P_1 \cdot l_1 = 3759.322$ in Lbs
$P_{2_1} = 73.754^{\#}$ ✓ $l_2 = 128.5$ in (LOAD @ UPPER SUSP. DISC) ; $M_{2_1} = P_{2_1} \times l_2 = 9477.389$ in Lbs
$P_{2_2} = 4.078^{\#}$ ✓ $l_2 = 128.5$ in (LOAD @ UPPER DISC) ; $M_{2_2} = P_{2_2} \times l_2 = 524.023$ in Lbs
$P_3 = 52.44^{\#}$ ✓ $l_3 = 107.5$ in (COMB. LOAD, INC. FLANGE LOAD @ UPPER MAST) ; $M_3 = P_3 \times l_3 = 5637.3$ in Lbs
$P_4 = 14.28^{\#}$ ✓ $l_4 = 95.5$ in (LOAD @ OMNI ANT.) ; $M_4 = P_4 \times l_4 = 1363.74$ in Lbs
$P_{5_1} = 1625.33^{\#}$ ✓ $l_5 = 86.5$ in (LOAD @ ANNULAR RING ASSY) ; $M_{5_1} = P_{5_1} \times l_5 = 140591.04$ in lbs
$P_{5_2} = 250.238$ $l_5 = 86.5$ in (LOAD – C'DISC + MISC. ITEMS MOUNTED) ; $M_{5_2} = P_{5_2} \times l_5 = 21645.58$ in lbs
$P_6 = 89.106^{\#}$ $l_6 = 66.5$ in (UPPER SECT. + FLANGES LOWER MAST) ; $M_6 = P_6 \times l_6 = 5925.549$ in lb
$P_{7_1} = 49.5^{\#}$ $l_7 = 48$ in (LOWER SUSP. SPINING) ; $M_{7_1} = P_{7_1} \times l_7 = 2376$ in lbs
$P_{7_2} = \underline{20.50^{\#}}$ $l_7 = 48$ in (LOWER SUSP. RAD. WNDX.) ; $M_{7_2} = P_{7_2} \times l_7 = \underline{984.0}$ in lbs
$2200.266^{\#}$ (PART. SUM.)
(PARTIAL SUM) = 192283.94

PARA 2.2.7 CONT'D.

$P_8 = 401.77\#$ — $l_8 = 25"$ (LOAD @ C BOX + LADDER ASS'Y) ; $M_8 = P_8 \times l_8 = 10044.25$ in Lbs

$P_9 = 24.01\#$ — $l_9 = 5"$ (LOAD @ LOWER MAST PORT.) ; $M_9 = P_9 \times l_9 = 120.05$ in Lbs

$P_{10} = \underline{3.575}\#$ — $l_{10} = 0.5"$ (LOAD @ LOWER FL. MAST.) ; $M_{10} = P_{10} \times l_{10} = 1.78$ in Lbs

Σ 429.355# (PART. HOR. WIND LOAD)

Σ 2200.266# (PART. HOR. WIND LOAD - SEE pp. #13) — (PARTIAL SUM) $\Sigma = 10166.08$ ✓ in Lbs

$\Sigma\Sigma$ 2629.62# $\simeq$ OK ✓ (SEE pp. #12)

OVERTURNING MOMENT ABOUT POINT "O" (SEE FIG #4, SH #13) DUE TO HORIZONTAL WIND LOAD

$$M_{TOTAL} = \sum_{n=1}^{n=10} M = M_1 + M_2 + \ldots\ldots + M_{10} = 202450.023 \text{ in Lbs} = \underline{16870.83} \text{ ft Lbs}$$

$$= \underline{16.870 \text{ K ft.}}$$

PARA 2.2.8 SUMMARY - WIND LOAD INTERFACE CONDITIONS AT TOWER TOP - NO ICE.

BASED ON LOADING CONDITIONS, SPECIFIED IN PARA 2.2.1 THE FOLLOWING LOADS APPLY AT THE ANTENNA-TOWER INTERFACE:

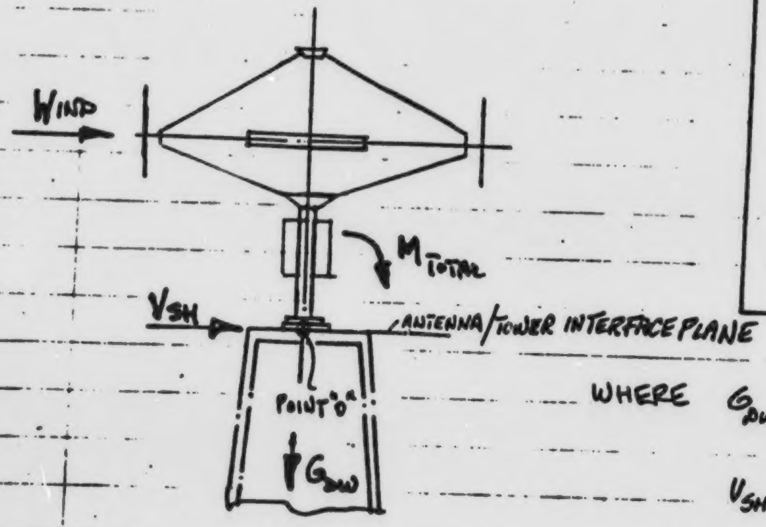


FIG #5

LOADING CONDITIONS:

@ ANTENNA/TOWER INTERFACE

$G_{DEADWEIGHT} = \underline{1086.09\#}$

$V_{SH} = \underline{2629.00\#}$

$M_{TOTAL} = \underline{16870.83 \text{ ft Lbs}}$

WHERE $G_{DW} = G_{DEADWEIGHT}$ = TOTAL DRY WEIGHT ANT. ASS'Y. [Lbs]

V_{SH} = TOTAL HORIZONTAL SHEAR LOAD DUE TO WINDS ON ANTENNA ASS'Y [Lbs]

M_{TOTAL} = OVERTURNING MOMENT ACTING ABOUT POINT "O" DUE TO WIND [Lbs ft.]

PARA 2.2.9 2" RADIAL ICE LOAD - ANTENNA ASSEMBLY WEIGHT ANALYSIS.

PARA 2.2.9.1 - ICE LOAD - ANNULAR RING ASS'Y.

@ JOINT CASTING $2 \times 4\frac{1}{2} \times 2 = 72 \text{ in}^3$

$+ 4\frac{5}{8} \times 2 \times 8 \times 2 = 148 \text{ in}^3$

$+ 8 \times 3\frac{1}{4} \times 2 = 52 \text{ in}^3$

$+ 8 \times 7 \times 2 = 112 \text{ in}^3$

$+ (2\frac{3}{4} + 4) \times 4 \times 4 \times 2 = 216 \text{ in}^3$

$+ 2 \times 7 \times 6\frac{1}{2} \times 2 = \underline{182 \text{ in}^3}$

$782 \text{ in}^3 = .4525 \text{ ft}^3 @ 56^{\#}/\text{cu ft} = 25.34^{\#}/\text{JOINT}$

@ DIPOLE $(33.858 + 4 - .375)(5.5^2 - 1.5^2)\frac{\pi}{4} = 828.29 \text{ in}^3 = .5394 \text{ ft}^3 @ 56^{\#}/\text{ft}^3 = 30.2^{\#}/\text{ea}$

DIPOLE SUPPORT $2 \times (7 \times 5.5 \times 4\frac{5}{8} - 3 \times 1.5 \times \frac{5}{8}) = 175.25 \text{ in}^3$

$2 \times (7 \times 5.5 \times 4\frac{7}{8} - 3 \times 1.5 \times \frac{3}{8}) = \underline{329.65 \text{ in}^3}$

$504.9 \text{ in}^3 = .33 \text{ cu ft} @ 56^{\#}/\text{ft}^3 = 18.50^{\#}$

C'POISE $(4.5^2 - .5^2)\frac{\pi}{4} \times (17.56 - 1.5) + \frac{4.5^2 \pi}{4} \times 2 = 284.078 \text{ in}^3 = .1856 \text{ ft}^3 @ 56^{\#}/\text{ft}^3 = 10.41^{\#}$

REAR OUTRIGGER $14.75 \times 6 \times 4\frac{3}{8} - 10.75 \times 2 \times \frac{3}{8} = 383.90 \text{ in}^3 = .2512 \text{ ft}^3 @ 56^{\#}/\text{ft}^3 = 14.06^{\#}$

@ ANNULAR RING - SINGLE LINK

$(18.552 - .25 \times 2) \times (7 \times 7 - 3 \times 3) + (8 \times 8 \times 2 \times 4.25 - 4 \times 4 \times 2 \times .25)$

$= 722.08 + 536 = 1258.08 \text{ in}^3 = .728 \text{ ft}^3 @ 56^{\#}/\text{ft}^3 = 40.77^{\#}/\text{ea}$

THUS - ANNULAR RING ASS'Y WITHOUT SUSPENSION SYSTEM - ICE LOAD

@ JOINT CASTINGS	- 25.34# × 32	= 810.88#
@ DIPOLE	- 30.2# × 32	= 966.40#
@ DIPOLE SUPPORT	- 18.5# × 32	= 592.00#
@ C'POISE	- 10.41# × 32	= 333.12#
@ REAR OUTRIGGER	- 14.06# × 32	= 449.92#
@ ANNULAR RING + FLANGES	40.77# × 32	= 1304.84#
	SUBTOTAL =	4457.16#

PARA 2.2.9.1 CONT'D.

UPPER SUSPENSION SYSTEM - NONMET. (REDUCED, 50% ONLY)

$$\frac{1}{2}\times\left[(109.45-6)\times(4.375^2-.375^2)\frac{\pi}{4}+\left(\frac{5^2\pi}{4}\times5.75-\frac{1^2\pi}{4}\times1.75\right)+\left(\frac{4.5^2\pi}{4}\times4-\frac{.5^2\pi}{4}\times2\right)\right]$$

$$=\frac{1}{2}(1543.73+174.75)=859.24\text{ in}^3=.5623\text{ ft}^3 @ 56\#/\text{ft}^3=\underline{31.49}\#/\tfrac{1}{2}\text{ length of upper rod}$$

LOWER SUSPENSION SYSTEM

$$\frac{1}{2}\times\Big[\underbrace{(96-6)\times(4.25^2-.25^2)\frac{\pi}{4}}_{1272.34\text{ in}^3}+\underbrace{\left(\frac{5^2\pi}{4}\times5.75-\frac{1^2\pi}{4}\times1.75\right)+\left(\frac{4.5^2\pi}{4}\times4-\frac{.5^2\pi}{4}\times2\right)}_{174.75\text{ in}^3}\Big]=$$

$$=\frac{1}{2}(1272.34+174.75)=723.54\text{ in}^3=.473\text{ ft}^3 @ 56\#/\text{ft}^3=\underline{26.517}\#/\tfrac{1}{2}\text{ length of lower rod}$$

GR. PLANE GUYS + COAX CABLES

$$\frac{1}{2}\times98.8\times\left(\frac{4.25^2\pi}{4}-\frac{.25^2\pi}{4}\right)=\frac{1396.75\text{ in}^3}{2}=\frac{.8083}{2}\text{ ft}^3 @ 56\#/\text{ft}^3=22.63\#/\text{ea}$$ without coax.

Where coax is applicable, add

$$\frac{1}{2}\times0.5\times98.8\times(4.435^2-.435^2)\frac{\pi}{4}=377.89\text{ in}^3=.2186\text{ ft}^3 @ 56\#/\text{ft}^3=12.24\#/\text{coax}$$

Note: only $\frac{1}{2}$ of coax iceload is used, assuming that coax is held close to guy wire all along.

Test antenna ice load:

$$\left(10.5\times8.25\times4.625-4.25\times6.5\times.625\right)+(6+2)\times(4.5^2-.5^2)\frac{\pi}{4}=$$

$$=383.375+125.663=509.03\text{ in}^3=.333\text{ ft}^3 @ 56\#/\text{ft}^3=18.65\#/\text{TEST ANT.}$$

$$\text{COAX ICE WEIGHT}=555\times(4.435^2-.435^2)\frac{\pi}{4}=\frac{841.47\text{ in}^3}{2}=\frac{.4869}{2}\text{ ft}^3$$

$$@ 56\#/\text{ft}^3=\frac{27.27}{2}\#/\text{COAX}$$

NOTE: ONLY $\frac{1}{2}$ OF COAX ICE LOAD IS CONSIDERED, ASSUMING THAT IT IS CLOSELY HELD ADJACENT TO ITS GUY WIRE ALL ALONG ITS PATH.

USING RELATIONSHIP ESTABLISHED FOR DRAWN. (SEE FIG # 2, pp. #4)

WHERE $P_{1ICE}=18.65\#$

$P_{2ICE}=13.635\#$

$$B_{ICE}=\frac{P_{1ICE}(R_1-R_3)+P_{2ICE}(R_1-R_3)}{R_1-R_4}=\frac{18.65(32.854)+13.635(60.354)}{87.854}$$

$$B_{ICE}=16.341\#$$

$$A_{ICE}=P_{1ICE}+P_{2ICE}-B_{ICE}=32.285-16.341=15.94\#$$

THUS @ ANNULAR RING $A_{ICE}=15.94\#/\text{TEST ANT.+COAX}$ (APPLIES AT "REDUCED" CONFIGURATION)

PARA 2.2.9.1 CONT'D.

TOTAL ICE LOAD ON ANNULAR RING DUE TO SUSPENSION + COAX:
(REDUCED)

DUE TO UPPER NONMET. SUSP. SYSTEM : 31.49# x 32 = 1007.68#
DUE TO LOWER " " " : 26.517# x 16 = 424.272#
DUE TO GROUND PLANE GUYS (WITHOUT COAX: 22.63# x 64 = 1448.32#
@ " " COAX LINES 12.24# x 32 = 391.68#
DUE TO 4-ONLY TEST ANTENNAS + COAXES 15.94 x 4 = 63.76#
PARTIAL SUM = 3335.71#

TOTAL ICE LOAD - ANNULAR RING ASS'Y INCL. SUSP. SYSTEM - REDUCED
ICELOAD @ ANNULAR RING ASS'Y = 4457.16#
ICE LOAD @ SUSP. SYSTEM, REDUCED = 3335.71#
ANNULAR RING ANTENNA = ICE LOAD = 7792.87#

DEADWEIGHT + ICE - ANNULAR RING ASS'Y WITH $\frac{1}{2}$ WEIGHT (INCL. ICE) OF SUSPENSION.

ICE LOAD = 7792.87#
DEADWEIGHT = 537.516#
ICE + DW, ANN. RING = 8330.38# INCL. $\frac{1}{2}$ OF SUSPENSION

PARA 2.2.9.2 ICE LOAD ON SUSPENSION, SUPPORTED "DIRECTLY" BY CENTERMAST

DUE TO UPPER NONMET. SUSP. SYSTEM = 31.49 x 32 = 1007.68#
" " LOWER " " " = 26.517 x 16 = 424.272#
" " GR. PL. GUYS " " = 22.63 x 64 = 1448.32#
" " GR. PL. COAX LINES = 12.24 x 32 = 391.68#
" " TEST ANT. + ITS COAX LINES = 16.341 x 4 = 65.36#
ICE LOAD ONLY-SUBTOTAL = 3337.316#

DEADWEIGHT OF ABOVE ITEMS REDUCED TO C'MAST:
(RE pp. 6)

DW. SUSP. SYST. + MISC. = 76.294#

COMBINED DW + ICE REDUCED TO C'MAST ASSY = 3413.61#

JH-18LT .C

PARA 2.2.9.3 ICE LOAD ON C'MAST ASS'Y. (2" RAD. ICE)

ON LIGHNING ARR. ROD

$(4.75^2 - .75^2)\frac{\pi}{4} \times 103.35 + \frac{4.75^2\pi}{4} \times 2 = 1821.2\,in^3 = 1.053\,ft^3$ @ $56^{\#}/ft^3 =$ 59.02#

ON CABLE FITTING + CLAMP

$86.56 \times (4.5^2 - 0.5^2)\frac{\pi}{4} + (6 \times 8 \times 5 - 2 \times 4 \times 1) = 1604.43\,in^3 = .928\,ft^3$ @ $56^{\#}/ft^3 =$ 51.99#

UPPER SPRING SUPPORT FLANGE

$\frac{18^2\pi}{4} \times 2 + (18^2 - 14^2)\frac{\pi}{4} \times 2\frac{1}{4} = 735.13\,in^3 = .425\,ft^3$ @ $56^{\#}/ft^3$ = 23.82#

EST. ~~ICE~~ DISPL ON FITTINGS

$32\left[(6^2 - 2^2)\frac{\pi}{4} \times 2.5 + \frac{6^2\pi}{4} \times 2\right] = 3820\,in^3 = 2.21\,ft^3$ @ $56^{\#}/ft^3$ = 123.80#

ON UPPER MAST - UPPER FLANGE

$\frac{(14.5^2 - 4.5^2)\pi}{4} \times 2 = 298\,in^3 = .172\,ft^3$ @ $56^{\#}/ft^3$ = 9.67#

ON LOWER FLANGE - UPPER MAST

$(14^2 - 10^2)\frac{\pi}{4} \times 2 = 307\,in^3 = .178\,ft^3$ @ $56^{\#}/ft^3$ = 9.97#

ON UPPER MAST

$(9.5 - 4.5)^2\frac{\pi}{4} \times (42 - 4\frac{5}{8}) = 2054.79\,in^3 = 1.189\,ft^3$ @ $56^{\#}/ft^3$ = 66.59#

ON OMNI ANTENNA

$(15.75 + 12)\pi + (12.14 - 4)4 \times (4.5^2 - .5^2)\frac{\pi}{4} = 2383.51\,in^3$

LEGS $5 \times 7 \times 4\frac{3}{16} \times 4 =$ $586.25\,in^3$

$2969.76\,in^3 = 1.718\,ft^3$ @ $56^{\#}/ft^3$ = 96.24#

INSULATORS

$(8^2 - 4^2)\frac{\pi}{4} \times 4 + \frac{8^2\pi}{4} \times 2 \times 4 = 552.92\,in^3 = .3199\,ft^3$ @ $56^{\#}/ft^3$ = 17.91#

ON GR. PLANE SUPPORT DISC ASS'Y:

@EXT. PER. ANGLES $50\pi \times 2 \times 8.25 = 2591.81\,in^3 = 1.4998\,ft^3$ @ $56^{\#}/ft^3 =$ 83.99#

$46\pi \times (\underbrace{4 \times 2 \times 2 - 2 \times .958}_{14.084}) = 2035.32\,in^3 = 1.177\,ft^3$ @ $56^{\#}/ft^3 =$ 65.95#

TOP of DISC $= \left(\frac{44^2\pi}{4} - \frac{10^2\pi}{4}\right) \times 2 - .6 \times \left(\frac{38^2 - 16^2}{4}\pi\right) \times 2 = 1764.32\,in^3 = 1.02\,ft^3$ @ $56^{\#}/ft^3 =$ 57.17#

BOTTOM DISC $1764.32 - \overbrace{4 \times \left(\frac{44}{2} - \frac{8.625}{2}\right) \times 3.5}^{279.625} = 1516.695\,in^3 = .877\,ft^3$ @ $56^{\#}/ft^3 =$ 49.15#

BOTTOM REINF ANGL. $(3.5 \times 4.25 - 2 \times .787)4 \times \left(\frac{44}{2} - \frac{8.625}{2}\right) = 1881.52\,in^3 = 1.08\,ft^3$ @ $56^{\#}/ft^3 =$ 60.97#

A/C WARNING LIGHTS

$2 \times \left[(8^2 - 4^2)\frac{\pi}{4} \times 9 + 2 \times \frac{8^2\pi}{4}\right] = 879.64\,in^3 = .509\,ft^3$ @ $56^{\#}/ft^3$ = 28.50#

ICE ON GR. PL. DISC = 345.73#

SUBTOTAL : 804.74# ✓

PARA 2.2.9.3 CONT'D.

@ UPPER FLANGE, LOWER MAST

$(16^2-12.625^2)\frac{\pi}{4}\times 3\frac{7}{8} = 234.088\ in^3 = .192\ ft^3$ @ 56#/ft³ = 10.77#

@ LOWER MAST

$(12.625^2-8.625^2)\frac{\pi}{4}\times\left[\underbrace{86.5-\left(3\frac{7}{8}+1\right)-4.25}_{77.525}\right] = 5175.97\ in^3 = 2.995\ ft^3$ @ 56#/ft³ = 167.723#

@ LOWER SUSPENSION - SUPPORT (SEE FIG #3, pp. #8 FOR REF)

$2\times2\times\Sigma A + (43.67^2-39.67^2)\frac{\pi}{4}\times4.25 = 7217.01\ in^3 = 4.176\ ft^3$ @ 56#/ft³ = 233.88#

@ CONTROL BOXES (2-ONLY)

$2\times\left[28\times34\times\left(4+8+1.25+\frac{3}{16}\right)-\left\{24\times30\times\left(8+1.25+\frac{3}{16}\right)\right\}\right] = 12009.4\ in^3 = 6.949\ ft^3$ @ 56#/ft³ = 389.193#

@ CONTROL BOX SUPPORTS

$4\times(2\times4\times28) = 896\ in^3 = 0.518\ ft^3$ @ 56#/ft³ = 29.03#

@ C'CABLE OUTLETS + COWLINGS - EST. (2-ONLY) INC. CABLES 27.84#

@ ACCESS LADDER + SUPPORTS

$2\times\left[(6\times6-2\times2)\times(11.06\times2+36.6)+4\times\frac{(4.75^2-.75^2)\pi}{4}\times6+8\times\frac{4.75^2\pi}{4}\times2\right]$

$=2\times\left[(32\times58.72)+4\underbrace{(103.67+283.52)}_{1548.76}\right] = 6855.6\ in^3 = 3.967\ ft^3$ @ 56#/ft³ = 222.17#

@ LOWER FLANGES

$(18^2-14^2)\frac{\pi}{4}\times3+(14^2-8.625^2)\frac{\pi}{4}\times2 = 492.61\ in^3 = .285\ ft^3$ @ 56#/ft³ = 15.96#

SUBTOTAL = 1096.56# ✓

SUMMARY - 2" RAD. ICE ONLY ON C'MAST ASS'Y. :

REDUCED LOAD - SUSPENSION ONLY : 3337.316# (REF. pp. 17)
C'MAST - UPPER SECT. ONLY : 809.74# (REF pp. 18)
C'MAST - LOWER SECT. ONLY : 1096.56# (REF. pp. 19)
2" ICE LOAD ON C'MAST ASS'Y $\Sigma_{2''ICE}$ = 5238.622#

PARA 2.2.9.4 COMBINED D.W. + 2" RAD. ICE LOAD ON ANT. ASS'Y.

MAJOR COMPONENT	DEADWEIGHT	ICE LOAD	ICE + DW
ANNULAR RING ASS'Y + RED. SUPP.	537.516#	7792.87#	8330.38#
C'MAST + RED. SUSP. SYST.	548.575	5238.622#	5787.197#
TOTAL LOAD:	1086.091#	13031.49#	14117.58#

Σ COMB. WEIGHT

2.2.10 WINDLOAD @ 2" RAD. ICE

APPLICABLE WIND LOADS — CSA S37-1976, pass 3.22, (b)

USE 50% WIND VELOCITY PRESSURE (psf) WITH APPLICABLE MULTIPLICATION FACTORS.

THUS — FOR FLAT SURFACES $p_{FL} = \frac{59.4}{2} = 29.7$ psf (SUBJECT TO CHANGE, REF. SPEC. PARA 3.2.6.6.1(a))

FOR ROUND SURFACES $p_r = \frac{39.6}{2} = 19.8$ psf

FOR GUYS $p_{guy} = \frac{47.52}{2} = 23.76$ psf

THE 50% LOWER WIND COND. CORRESP. TO A 152.41 km/h WIND OR 94.73 mph

2.2.10.1 WIND LOAD, (WITH 2" ICE) ANNULAR RING ASS'Y + SUSPENSION.

a.) FRONTAL PROJECTION — SINGLE JOINT ASS'Y

FRONT $8 \times 8.5 = 68\ in^2 = .4722\ ft^2$ @ $p = \frac{18}{2} \times 1.1 \times 2 \times 1.25 = 24.75$ psf = 11.6875#

for this case only (flat)

where $C_p = 1.5 - R = 1.5 - \frac{2}{8} = 1.25$

REAR STRUT $4.375 \times (15-8) = 30.625\ in^2 = 0.2126\ ft^2$ @ $p = \frac{18}{2} \times 1.1 \times 2 \times 1.2 = 23.76$ psf = 5.05#

where $C_p = 1.5 - R = 1.2$ because $R = \frac{2}{0.375} = 5.33 > 0.3$

DIPOLE = $5.5 \times (33.858 + 4 - 8) = 164.219\ in^2 = 1.140\ ft^2$ (Round) @ 19.8 psf = 22.57#

C POISE —

39.32#

b.) SIDE PROJECTION — SINGLE JOINT ASS'Y

BODY SIDE EL. $8 \times 11 - (6 \times 11) = 22\ in^2 = 0.1527\ ft^2$ @ 24.75 psf = 3.78#

REAR STRUT $6 \times (11 + 4 - 8) = 42\ in^2 = 0.29\ ft^2$ @ 23.7 psf = 6.91#

DIPOLE $5.5 \times (33.858 + 4 - 8) = 164.219\ in^2 = 1.140\ ft^2$ (Round) @ 19.8 psf = 22.57#

C'POISE $4.5 \times 16.81 = 75.645\ in^2 = 0.525\ ft^2$ (Round) @ 19.8 psf = 10.40#

DIPOLE SUPPORTS $3 \times 4.5 \times 4.75 = 64.12\ in^2 = .44\ ft^2$ (Flat) @ 23.7 psf = 24.14#

67.815#

USING AVERAGE — $\frac{67.815 + 39.32}{2} = 53.56$#/JOINT WILL BE USED IN FRONT

53.56#

@ REAR SEGMENT, DELETE C'POISE = 10.4#

DIPOLE SUPP. = 24.14

34.54#

SO AVE = $\frac{(67.815 - 34.54) + 39.32}{2} = 36.29$#/JOINT WILL BE USED @ REAR

WIND LOAD JOINTS, INCL. DIPOLE ASS'Y.

$16 \times 53.56 + 16 \times 36.29 =$ 1437.60#

WIND LOAD DUE TO ANNULAR RING (3" SQ. TUBING)

$(3 + 4) \times 111.854 \times 2 = 1565.95\ in^2 = 10.87\ ft^2$ @ 23.76 psf

= [illegible]#

2.2.10.1 CONT'D

CONSIDERING TRASPARENCY FACTOR = 2,

ANNULAR RING ASS'Y WIND RESISTANCE 2 × 258.38 = 516.76#

REDUCED WIND LOAD - SUSPENSION SYSTEM:

UPPER RODS

$\frac{1}{2} \times 32 \times (42 - 4.75) \times 4.375 = 2607.5\ in^2 = 18.107\ ft^2$ @ 23.76 psf (guy) = 430.23#

LOWER RODS

$\frac{1}{2} \times 16 \times 31.07 \times 4.25 = 1056.38\ in^2 = 7.33\ ft^2$ @ 23.76 psf (guy) = 174.30#

GR. PL. GUYS @ 25% SHADOW

$0.5 \times 0.25 \times 4.125 = 98.8 \times 64 = 3260.4\ in^2 = 22.64\ ft^2$ @ 23.76 psf (guy) = 537.96#

COAX CABLES, ROUND 25% SHADOW

$0.5 \times 0.25 \times 4.435 \times 98.8 \times 32 = 1752.71\ in^2 = 12.17\ ft^2$ @ 19.8 psf (round) = 240.99#

TEST ANTENNAS

$10.25 \times 4.25 = 43.56\ in^2 = 0.3025\ ft^2$ @ 23.76 (flat, with $C_p = 1.2$) = 7.18#/ea

CONNECTOR = $4.75 \times 4\ in = 19\ in^2 = 0.131\ ft^2$ @ 19.8 psf = 2.61#/ea

TUBE = $4.5 \times 8\ in = 36\ in^2 = .25\ ft^2$ @ 19.8 psf = 4.95#/ea

14.74#/ea

SINCE THERE ARE 4-TEST ANT.,
ASSIGN 50% TO ANNULAR RING

4 × 14.74 = 58.96#, 50% = 29.48#

+ COAX $4.435 \times 75 = 332.625\ in^2 = 2.308\ ft^2$ @ 19.8 psf = 45.73 ea

FROM 4-COAXES @ 50% ON ANN. RING

4 × 45.73 × 0.5 = 91.47#

PARTIAL SUM 2021.19

(FROM pp. 20) SUM 1437.60

TOTAL HOR. WIND LOAD - ANNULAR RING ASS'Y = 3458.79#

2.2.10.2 WINDLOAD @ 2" RADIAL ICE HOR. GUY + MISC. OTHER LOADS REDUCED TO CENTERMAST ASS'Y.

a.) WIND LOAD DUE TO UPPER SUSP. SYST.	430.23# ✓
b.) WIND LOAD " " LOWER " "	174.30# ✓
c.) WIND LOAD " " GR. PLANE GUYS	537.96# ✓
d.) WIND LOAD DUE TO COAX CABLES	240.99# ✓
e.) WIND LOAD DUE TO TEST ANTENNAS	29.48# ✓
f.) WIND LOAD " " " " COAXES	91.47# ✓
	1504.43# ✓ → 1504.43# ✓

2.2.10.3 WIND LOAD ON C'MAST ASS'Y @ 2" RADIAL ICE.

ON LIGHTNING ROD 4.75 DIA × 104 = 494 in^2 = 3.43 ft^2 @ 19.8 psf (round)	= 67.92# ✓
ON UPPER DISC 18.83 DIA × 5" = 94.15 in^2 = .653 ft^2 @ 19.8 " "	= 12.94#
@ UPPER FLANGE 14 × 2.25 = 31.5 in^2 = .218 ft^2 @ 19.8 psf (round)	= 4.33# } 17.27
@ " MAST, TUBE 8.5 × (41-4) = 314.5 in^2 = 2.18 ft^2 @ 19.8 psf (")	= 43.24#
@ LOWER FLANGE 14 × 2.375 = 33.25 in^2 = .230 ft^2 @ 19.8 psf (")	= 4.57# } 47.81
@ AIRCRAFT WARN. LIGHTS 2 × 8.5 × 12 = 204 in^2 = 1.416 ft^2 @ 19.8 " (")	= 28.05# ✓
@ OMNI ANT. UPPER RING 15.75 × 4.5 = 70.875 in^2	
LOWER " 12 × 4.5 = 54.00 in^2	
LEGS 4 × 12.14 × 4.5 = 218.52 in^2 = 2.38 ft^2	
343.395 in^2 @ 19.8 psf (round)	= 47.21# ✓
SUPPORT 4 × 4.187 × 7 = 117.23 in^2 = .814 ft^2 @ 23.76 (FLAT)	= 19.34# ✓
@ INSULATORS 4 × 6 × 5 = 120 in^2 = .833 ft^2 @ 19.8 psf (round)	= 16.5# ✓
@ GROUND PLANE — DISC = 8.25 × 52 = 429 in^2 = 2.979 ft^2 @ 19.8 psf (round)	= 58.98# ✓
@ SPACERS AND (TOP OF MAST LOWER FLANGE = 14 × $3\frac{7}{8}$ = 54.25 in^2 = .376 ft^2 @ 19.8 psi (")	= 7.45# ✓
@ LOWER MAST 12.625 × (86.5 - 3.875 - 4 - 36.25 - 8.5) = = 427.67 in^2 = 2.97 ft^2 @ 19.8 psf (round)	= 58.8# ✓
@ LOWER SUSP. - SPINNING 44 × 8.5 = 374 in^2 = 2.597 ft^2 @ 19.8 psf (round)	= 51.42# ✓
@ CONTROL BOXES (FRONT, 1-ONLY) 28 × 36.25 = 1015 in^2 = 7.048 ft^2 @ 28.28 psf (flat)	= 199.357#
@ CLIMBING STRUTS 2 × 40 × 6 = 480 in^2 = 3.33 ft^2 @ 23.76 psf (flat)	= 79.19# } 330.797 ✓
2 × 4 × 10 × 4.75 = 380 in^2 = 2.638 ft^2 @ 19.8 psf (round)	= 52.25#
@ LOWER MTG FL. #1; 16 × .2.5 = 40 in^2 = .277 ft^2 @ 19.8 psf (")	= 5.5# ✓
@ " " " #2; 18 × 0.5 = 9 in^2 = 0.0625 ft^2 @ 19.8 psf (")	= 1.23# ✓
C'MAST-HOR WIND LOAD - SUBTOTAL	= 758.277# ✓
HOR. WIND LOAD C'MAST DUE TO GUYS	= 1504.43# ✓
TOTAL HOR. WINDLOAD ON C'MAST ASS'Y (WITH 2" ICE)	= 2262.707# ✓

PARA 2.2.10.4 TOTAL WIND LOAD - ANTENNA ASS'Y @ 2" RAD. ICE.

WIND LOAD DUE TO ANNULAR RING ASS'Y INCL. SUSP.	3458.79 # ✓
" " " " C' MAST ASS'Y, INCL. RED. SUSP. LOADS	2262.70 # ✓
TOTAL HOR. WIND LOAD ≤≤ TOTAL =	5721.49 # ✓

CALC. OF OVERTURNING MOMENT: (FOR INFO. SEE pp. 13 AND FIG # 4)

LOCATION OF WINDLOADS SAME AS SHOWN ON ABOVE REFERENCE:

WHERE ✓ $P'_1 = 67.92$ # ✓ @ L. Arrester	$l_1 = 178.675$ in	$M'_1 = P_1 l_1 = 12185.60$ in Lbs ✓
✓ $P'_{2_1} = 430.23$ # ✓ @ upper Susp.	$l_2 = 128.5$ in	$M'_{2_1} = P'_{2_1} l_2 = 55284.55$ in Lbs ✓
✓ $P'_{2_2} = 17.27$ # ✓ @ upper Disc	$l_2 = 128.5$ in	$M'_{2,2} = P'_{2_2} l_2 = 2219.195$ in Lbs ✓
✓ $P'_3 = 47.87$ # upper mast + flanges	$l_3 = 107.5$ in	$M'_3 = P'_3 \cdot l_3 = 5146.025$ in Lbs ✓
✓ $P'_4 = 47.21$ # ✓ @ Dome Ant.	$l_4 = 95.5$ in	$M'_4 = P'_4 l_4 = 4508.55$ in Lbs ✓
✓ $P'_{5_1} = 3458.79$ # ✓ @ Annular Ant.	$l_5 = 86.5$ in	$M'_{5_1} = P'_{5_1} l_5 = 299185.335$ in Lbs ✓
→ $P'_{5_2} = 1030.22$ # @ C Disc + Misc	$l_5 = 86.5$ in	$M'_{5_2} = P'_{5_2} l_5 = 89144.03$ in Lbs ✓
✓ $P'_6 = 48.8$ # @ flanges + upper sect. lower mast	$l_6 = 66.5$ in	$M'_6 = P'_6 l_6 = 3245.20$ in Lbs ✓
✓ $P'_{7_1} = 51.42$ # ✓ lower Susp. Spid.	$l_7 = 48.00$ in	$M'_{7_1} = P'_{7_1} l_7 = 2468.16$ in Lbs ✓
✓ $P'_{7_2} = 174.30$ # ✓ @ lower Susp.	$l_7 = 48.00$ in	$M'_{7_2} = P'_{7_2} l_7 = 8366.4$ in Lbs
✓ $P'_{8_1} = 330.797$ # ✓ @ C Box + Saddles	$l_8 = 25.00$ in	$M'_8 = P'_8 l_8 = 8269.93$ in Lbs
✓ $P'_9 = 10.00$ # @ lower mast	$l_9 = 5.00$ in	$M'_9 = P'_9 l_9 = 50.00$ in Lbs
✓ $P'_{10} = 6.73$ # ✓ @ lower Flanges	$l_{10} = 0.5$ in	$M'_{10} = P'_{10} l_{10} = 3.37$ in Lbs

st. pl. guys, cabl 537.96 ✓
coax cabl + 240.99 ✓
Test ant. 29.48
Test ant. coax 91.47 ✓
899.90
+ 130.32
1030.22

A/c W.L. 28.05 ✓
support 19.34 ✓
insulator 16.5 ✓
C.P. Disc 58.98 ✓
Spacers 7.45 ✓
130.32

$\Sigma P' = 5721.09$ # ✓ ok.

$\Sigma M' = 489996.35$ in Lbs

Σ Moment = $\Sigma M' = 489996.35$ in Lbs = 40833.029 ft Lbs
= 40.833 k ft.

LOADING CONDITIONS ON TOWER @ 2" RAD ICE + WINDS

$G_{DEADW. ANT.}$ = 1086.09 # (REF. SEE FIG # 4, pp. # 13)

2" RAD. ICE LOAD = 13031.49 #

COMBINED DW + ICE = 14117.58 #

HORIZONTAL SHEAR LOAD @ TOWER INTERFACE : V_{SH} = 5721.49 #

OVERTURNING MOMENT ABOUT POINT "0" $M_{ICE + W}$ = 40833.03 ft Lbs

PARA 2.3 ALTERNATIVE LOADING CONDITIONS ON ANTENNA SYSTEM.

CALCULATE ALTERNATIVE LOADING CONDITIONS WITH SAME PHYSICAL ANTENNA CONFIGURATION, IDENTICAL WIND LOAD BUT ICE LOADING ZONE II (CSA STANDARD S37-1976, para 3.2.4.2) WITH 1" RADIAL ICE ONLY.

PARA 2.3.1 1" RADIAL ICE LOAD - ANTENNA ASS'Y - WEIGHT ANALYSIS.

PARA 2.3.1.1 ICE LOAD - ANNULAR RING ASS'Y.

JOINT CASTING $6 \times 4.5 \times 1 = 27 in^3$

$4\frac{5}{8} \times 2 \times 7 \times 1 = 64.75 in^3$

$7 \times 3\frac{1}{4} \times 2 = 45.5 in^3$

$7 \times 6 \times 1 = 42.0 in^3$

$(2.75 + 2) \times 4 \times 4 \times 1 = 88.0 in^3$

$2 \times 7 \times 4.5 \times 1 = \underline{63.0 in^3}$

$330.25 in^3 = 0.191 ft^3 @ 56^{\#}/ft^3 = 10.7025^{\#}/JOINT$

DIPOLE $(33.858 + 2 - .375)(3.5^2 - 1.5^2)\frac{\pi}{4} = 278.682 in^3 = .1612 ft^3 @ -"- = 9.03^{\#}/ea$

DIPOLE SUPPORT $1(5 \times 3.5 \times 2\frac{5}{8} - 3 \times 1.5 \times \frac{5}{8}) = 43.125 in^3$

$2(5 \times 3.5 \times 2\frac{3}{8} - 3 \times 1.5 \times \frac{3}{8}) = \underline{79.75 in^3}$

$122.875 in^3 = 0.0711 ft^3 @ 56^{\#}/ft^3 = 3.98^{\#}/ea$

C' POISE $(2.5^2 - .5^2)\frac{\pi}{4} \times (17.56 - 1.5) + \frac{2.5^2 \pi}{4} \times 1 = 80.89 in^3 = 0.0468 ft^3 @ 56^{\#}/ft^3 = 2.62^{\#}/ea$

REAR OUTRIGGER $12.75 \times 4 \times 2.375 - 10.75 \times 2 \times \frac{3}{8} = 113.06 in^3 = .065 ft^3 @ 56^{\#}/ft^3 = 3.66^{\#}/ea$

ANNULAR RING - SINGLE LINK

$(18.552 - .25 \times 2)(5 \times 5 - 3 \times 3) + (6 \times 6 \times 2 \times 1.25 - 4 \times 4 \times 2 \times .25)$

$= \underline{370.832 in^3 = .214 ft^3 @ 56^{\#}/ft^3 = 12.01^{\#}/ea}$

THUS WEIGHT OF 1" ICE @ ANNULAR RING - WITHOUT SUSP. SYSTEM:

@ JOINT CASTING	- 10.7025#	× 32	= 342.48#
@ DIPOLE	9.03#	× 32	= 288.96#
@ DIPOLE SUPPORT	3.98#	× 32	= 127.36#
@ C' POISE	2.62#	× 32	= 83.84#
@ REAR OUTRIGGER	3.66#	× 32	= 117.12#
@ ANNULAR RING + FLANGES	12.01#	× 32	= 384.32#
		SUBTOTAL =	1344.08# ✓

PARA 2.3.1.1 CONT'D.

ICE LOAD (1"RAD. ICE) ON SUSPENSION SYSTEM:

@ UPPER SUSPENSION SYSTEM - NONMETALIC, 50% ON ANNULAR RING ONLY

$$\frac{1}{2}\left[(109.45-5)\times(2.375^2-.375)\frac{\pi}{4}+\left(\frac{3^2\pi}{4}\times 4.75-\frac{1^2\pi}{4}\times 1.75\right)+\frac{2.5^2\pi}{4}\times 8-.\left(\frac{1^2\pi}{4}\times 1\right)\right]$$

$$=0.5\left(451.19+32.20+14.529\right)=497.92\,\text{in}^3=.288\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=16.13^{\#}/\text{ea @}\tfrac{1}{2}\text{ length}$$

@ LOWER SUSPENSION SYSTEM - NONMET. 50% ON ANNULAR RING ONLY:

$$\frac{1}{2}\left[(96-5)\times(2.25^2-.75^2)\frac{\pi}{4}+\left(\frac{3^2\pi}{4}\times 4.75-\frac{1^2\pi}{4}\times 1.75\right)+\left(\frac{2.5^2\pi}{4}\times 3-.\frac{5^2\pi}{4}\times 2\right)\right]$$

$$=0.5\left(357.35+32.201+14.33\right)=403.881\,\text{in}^3=0.2337\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=13.088\,{}^{\#}/\text{ea}\tfrac{1}{2}\text{ length}$$

@ GROUND PLANE GUYS AND COAX CABLES

$$\frac{1}{2}\times 98.8\left(\frac{2.25^2\pi}{4}-\frac{.75^2\pi}{4}\right)=193.99\,\text{in}^3=0.1122\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=6.236^{\#}/\text{ea}\tfrac{1}{2}\text{ length}$$

WITHOUT COAX.

WHERE COAX IS APPLICABLE ADD

$$\frac{1}{2}\times 0.5\times 98.8\left(2.435^2-.435^2\right)\frac{\pi}{4}=111.35\,\text{in}^3=0.0644\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=3.608^{\#}/\text{ea}\tfrac{1}{2}\text{ length}$$

@ TEST ANTENNAS

$$\frac{1}{2}\left(8.5\times 6.25\times 2.625-4.25\times 6.5\times .625\right)+(6+1)\left(2.5^2-.5^2\right)\frac{\pi}{4}=$$

$$\frac{1}{2}\left(139.453+32.986\right)=86.219\,\text{in}^3=0.0498\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=2.79^{\#}/\tfrac{1}{2}\text{ w/ANT.}$$

TEST ANT. COAX ICE WEIGHT =

$$\frac{1}{2}\times 55.5\left(2.435^2-.435^2\right)\frac{\pi}{4}=\frac{250.20\,\text{in}^3}{2}=125.102\,\text{in}^3=.072\,\text{ft}^3 @ 56^{\#}/\text{ft}^3=4.05^{\#}/\tfrac{1}{2}\text{ length coax}$$

TOTAL ICE LOAD (1"RAD. ICE CASE) ON ANNULAR RING DUE TO SUSPENSION SYSTEM, COAX + TEST ANT. AND IT'S COAX

DUE TO UPPER SUSP. SYSTEM : 32 × 16.13# = 516.16#

DUE TO LOWER " " : 16 × 13.088# = 209.408#

DUE TO GROUND PLANE GUYS (NO COAX) : 64 × 6.236# = 399.104#

" " " " COAX LINES : 32 × 3.608# = 115.456#

DUE TO 4-ONLY TEST ANTENNAS : 4 × 2.79# = 11.16#

" " " " " " COAXLINES : 4 × 4.05# = 16.2#

ICE LOAD ONLY - SUBTOTAL = 1267.488#

1" ICELOAD ANNULAR RING ASS'Y = 1344.08#

TOTAL WEIGHT OF 1" RADIAL ICE - ANNULAR RING ASS'Y INCL RED. WEIGHT ON SUSP. = 2611.568#

PARA 2.3.1.1 CONT'D.

COMB. DEADWEIGHT + 1" RAD. ICE ON ANNULAR RING ASS'Y, INCL. SUSPENSION

Σ ICE LOAD - COMBINED	2611·568#	(1" RAD. ICE)
TOTAL DEADWEIGHT	537.516	
ICE + DW ΣΣ =	3149·084#	@ 1" RAD. ICE.

PARA 2.3.1.2 TRANSFER OF ICELOAD (1" RAD ICE) FROM SUSPENSION DIRECTLY TO C'MAST (RED. TO C'MAST)

DUE TO UPPER NONMET. SUPPORT	516·16#
" " LOWER " "	209·408#
" " GR. PL. GUYS	399·104#
" " " " COAXES	115·456#
" " TEST ANTENNAS	11·16#
" " " " – COAXES	16·2
Σ ICE LOAD SUSP. =	1267·488#
+ DW. OF SUSP. =	76·294#

DW + ICE LOAD $\left\{ \begin{array}{l} \text{TEST ANT + COAXES + SUSP.} \\ \text{50\% – REDUCED TO C'MAST} \end{array} \right)$ = 1343·782# → 1343·782#

PARA 2.3.1.3 ICE LOAD ON C'MAST ASS'Y (1" RAD ICE)

ON LIGHTNING ARR. ROD

$(2.75^2 - .75^2)\frac{\pi}{4} = 103.35 + \frac{2.75^2\pi}{4} \times 1 = 574.135\ in^3 = .333\ ft^3 @ 56^{\#}/ft^3 = 18.60^{\#}$

ON CABLE FITTINGS + CLAMS

$86.56 \times (2.5^2 - 0.5^2)\frac{\pi}{4} + (4 \times 6 \times 3 - 2 \times 4 \times 1) = 471.90\ in^3 = .308\ ft^3 @ 56^{\#}/ft^3 = 17.29^{\#}$

UPPER SPRING SUPPORT FRAME

$\frac{16^2\pi}{4} \times 1 + (16^2 - 14)\frac{\pi}{4}\ 1.25 = 259.966\ in^3 - .150\ ft^3 @ 56^{\#}/ft^3 = 8.42^{\#}$

EST. ICE DISPL. ON FITTINGS

$32\left[(4^2 - 2^2)\frac{\pi}{4} \times 2.5 + \frac{4^2\pi}{4} \times 1\right] = 1156.106\ in^3 = .6690\ ft^3 @ 56^{\#}/cu\,ft = 37.466^{\#}$

UPPER MAST – UPPER FLANGE

$(12.5^2 - 4.5^2)\frac{\pi}{4} \times 1 = 106.814\ in^3 = 0.0618\ ft^3 @ 56^{\#}/ft^3 = 3.46^{\#}$

LOWER FLANGE – UPPER MAST

$(12^2 - 10^2)\frac{\pi}{4} \times 1 = 34.55\ in^3 = 0.01999\ ft^3 @ 56^{\#}/ft^3 = 1.119^{\#}$

UPPER MAST

$(6.5^2 - 4.5^2)\frac{\pi}{4} \times (42 - 2\tfrac{5}{8}) = 680.35\ in^3 = .3937\ ft^3 @ 56^{\#}/ft^3 = 22.048^{\#}$

SUBTOTAL: 108.403#

PARA 23.1.3 CONT'D.

OMNI-ANTENNA

$$(15.75+12)\pi+(12.14-2)\times(2.5^2-.5^2)\frac{\pi}{4}=472.937\,in^3=.273\,ft^3 @ 56\#/ft^3= 15.326\#$$

LEGS - OMNI-ANTENNA

$$3\times5\times2\tfrac{3}{16}\times4= \quad =131.25\,in^3=0.075\,ft^3 @ 56\#/ft^3=4.25\#$$

19.57#

INSULATORS

$$(6^2-4^2)\frac{\pi}{4}\times4+\frac{6^2\pi}{4}\times1\times4=175.929\,in^3=.1018\,ft^3 @ 56\#/ft^3=5.701\#$$

GR. PL. SUPPORT DISC

EXT. PER. ANGLES

$$50\pi\times1\times6.25=981.747\,in^3=.568\,ft^3 @ 56\#/ft^3= 31.815\#$$

$$47\pi\times(3\times1\times2-2\times.158)=603.02\,in^3=.3489\,ft^3 @ 56\#/ft^3= 19.54\#$$

TOP OF DISC

$$\left(\frac{44^2\pi}{4}-\frac{10^2\pi}{4}\right)\times1-.6\times(38^2-16^2)\frac{\pi}{4}\times1=882.159\,in^3=.510\,ft^3 @ 56\#/ft^3= 28.58\#$$

BOTTOM OF DISC

$$882.159-2\times\left(\frac{44}{2}-\frac{8.625}{2}\right)3.5=697.971\,in^3=.409\,ft^3 @ 56\#/ft^3= 22.61\#$$

BOTTOM REINF. ANGLES

$$(2.5\times2.25-2\times.789)\times4\times\left(\frac{44}{2}-\frac{8.625}{2}\right)= =425.94\,in^3=.246\,ft^3 @ 56\#/ft^3 = 13.80\#$$

AIRCRAFT WARNING LIGHTS

$$2\left[(6^2-4^2)\frac{\pi}{4}\times9+1\times\frac{6^2\pi}{4}\right]=339.29\,in^3=.196\,ft^3 @ 56\#/ft^3 = 10.99\#$$

127.335# - ICE LOAD ON C'DISC

UPPER FLANGE, LOWER MAST

$$(14^2-12.625^2)\frac{\pi}{4}\times1\tfrac{7}{8}=53.91\,in^3=0.031\,ft^3 @ 56\#/ft^3 = 1.747\#$$

LOWER MAST

$$(10.625^2-8.625^2)\frac{\pi}{4}\times\left[86.5-(1.875+1)-2.25\right]=2460.60\,in^3 =1.423\,ft^3 @ 56\#/ft^3 = 79.74\#$$

LOWER SUSPENSION SUPPORT (SEE FIG. 3 pp. #8 FOR REF.)

$$2\times1\times\Sigma\overset{1576.07\,in^2}{A}+(42.67^2-39.67^2)\frac{\pi}{4}\times2.25=4004.92\,in^3=2.31\,ft^3 @ 56\#/ft^3= 129.789\#$$

CONTROL BOXES + SUPPORTS - 2-ONLY

$$2\left[26\times32\times(\underbrace{2+8+1.75+\tfrac{3}{16}}_{11.437})-\left(24\times30\times(\underbrace{8+1.25+\tfrac{3}{16}}_{9.437})\right)\right]=5441.88\,in^3 =3149\,ft^3 @ 56\#/ft^3= 176.357\#$$

@ CABLE OUTLETS AND COWLINGS EST. 2-ONLY, INCL. CABLES = 12.00#

ACCESS LADDERS AND SUPPORTS

$$2\times\left[(4\times4-2\times2)\times(11.06+2\times36.6)+4\times\left(\frac{(2.75^2-.75^2)\pi}{4}\times8+8\times\frac{2.75^2\pi}{4}\times1\right)\right] =1374.83\,in^3=.795\,ft^3 @ 56\#/ft^3 = 44.55\#$$

@ LOWER FLANGES

$$(16^2-14^2)\frac{\pi}{4}\times2+(14^2-8.625^2)\frac{\pi}{4}\times1=189.75\,in^3=.1098\,ft^3 @ 56\#/ft^3=6.149\#$$

TOTAL = 602.947#

PARA 2.3.1.3 CONT'D

SUMMARY – 1" RAD. ICELOAD – C'MAST ASS'Y:

Σ ICELOAD, DUE TO SUSP. SYSTEM = 1267.488#
(REF. SH#26)

PARTIAL SUM, ICE LOAD ON MAST = 108.403#
(REF. SH.#27)

PARTIAL SUM, ICE LOAD ON MAST = 602.947#
(REF. SH#28)

TOTAL ICE LOAD ON C'MAST ONLY = 1978.838# (1" RAD. ICE)

PARA 2.3.1.4 COMBINED DW + 1" RAD. ICE LOAD ON ANT. ASS'Y.

MAJOR COMPONENTS	DEADWEIGHT	ICE LOAD	ICE + DW
ANNULAR RING ASS'Y (INCL. RED. SUSP.)	537.516#	2611.568#	3149.08#
C'MAST + SUSP. SYSTEM (RED)	548.571#	1978.838#	2527.409#
TOTAL LOADS Σ	1086.091#	4590.406#	5676.488#

PARA 2.3.2 WINDLOAD @ 1" RADIAL ICE.

APPLICABLE LOADING CONDITIONS FOR WIND ARE IDENTICAL TO THE ONCE USED @ THE 2" RAD ICE WINDLOAD CASE, SEE REF. PARA 2.2.10, SH#20

PARA 2.3.2.1 WIND LOAD (1" RAD ICE) ANNULAR RING AND SUSP. SYSTEM.

a.) FRONTAL PROJECTION – SINGLE JOINT ASS'Y:

FRONT 6×6.5 = 39 in² = .2708 ft² @ 27.75 psf = 7.51#

REAR STRUT = 2.375 (13-6) = 16.625 in² = .115 ft² @ 23.7 psf = 2.736#

DIPOLE = 3.5 (33.858 + 2 - 6) = 104.503 = .7257 ft² @ 19.8 psf (round) = 14.369#

C POISE = —

24.615#

b.) SIDE PROJECTION – SINGLE JOINT ASS'Y:

BODY – SIDE EL (6×11) – (.5×11) = 11 in² = .076 ft² @ 24.75 psf = 1.89#

REAR STRUT 4×(11+2-5) = 32 in² = .222 ft² @ 23.7 psf = 5.26#

DIPOLE 3.5×(33.858+2-6) = 104.503 in² = .7257 ft² @ 19.8 psf = 14.367#

C'POISE 2.5×16.81 = 42.025 in² = .2918 ft² @ 19.8 psf = 5.778#

DIPOLE SUPPORTS 3×2.5×2.75 = 20.625 in² = .143 ft² @ 23.7 psf = 3.39#

30.687#

PARA 2.3.2.1 CONT'D.

USING THE AVERAGE WIND LOAD BETW. SIDE AND FRONT CONFIGURATION

$$\frac{24.615 + 30.687}{2} = 27.651\,\#/\text{JOINT}$$ WILL BE USED (FRONT ONLY)

FOR REAR SEGMENT, DELETE WINDLOAD ON C'POISE, THUS

$$\frac{24.615 + (30.687 - 5.778)}{2} = 24.762\,\#/\text{JOINT}$$ WILL BE USED (REAR ONLY)

WIND LOAD ON JOINTS THEREFORE ARE:

16 × 27.651 + 16 × 24.762 = 838.608# ⟶ 838.605#

WIND LOAD ON ANNULAR RING (3" SQ. TUBING)

(3+2) 111.854 × 2 = 1118.52 in^2 = 7.767 ft^2 @ 23.76 psf =

(with Transp factor = 2) = 184.555#

2 × 184.555 = 369.111#

REDUCED WIND LOAD – SUSPENSION SYSTEM:

UPPER RODS:

$\frac{1}{2}$ × 32 × (42 − 4.25) × 2.375 = 1434.5 in^2 = 9.96 ft^2 @ 23.76 psf (guy) = 236.69#

LOWER RODS

$\frac{1}{2}$ × 16 × 31.07 × 2.25 = 559.26 in^2 = 3.88 ft^2 @ 23.76 psf (guy) = 92.28#

GR. PL. GUYS @ 25% TRANSP. (SHADOW)

0.5 × .25 × 2.125 × 98.8 × 64 = 1679.6 in^2 = 11.66 ft^2 @ 23.76 psf (guy) = 277.134#

COAX CABLES, @ 25% TRANSP. (SHADOW)

0.5 × .25 × 2.435 × 98.8 × 32 = 962.312 in^2 = 6.682 ft^2 @ 19.8 psf (round) = 132.32#

TEST ANTENNAS 8.25 × 2.75 = 18.56 in^2 = .128 ft^2 @ 23.76 psf = 3.06#

CONNECTOR 2.75 × 3 = 8.25 in^2 = .057 ft^2 @ 19.8 psf = 1.13#

TUBE 2.5 × 7 = 17.5 in^2 = .121 ft^2 @ 19.8 psf = 2.40#

6.59#/TEST ANT.

ASSIGN 50% OF LOAD TO ANN. RING, 4-TEST ANT:

4 × 0.5 × 6.59 = 13.19#

TEST ANTENNA COAX CABLES

2.435 × 75 = 182.625 in^2 = 1.268 ft^2 @ 19.8 psf = 25.11#

ASSIGN 50% OF 4-COAXES TO ANN. RING:

4 × 0.5 × 25.11 = 50.22#

TOTAL HOR. WINDLOAD – ANNULAR RING ASS'Y = 2009.55#

PARA 2.3.2.2 **WINDLOAD @ 1" RAD. ICE**
HOR. GUY + MISC. OTHER LOADS REDUCED TO CENTERMAST ASS'Y.

a.) WINDLOAD DUE TO UPPER SUSP. SYSTEM = 236.69# ✓
b.) " " " LOWER " " = 92.28# ✓
c.) " " " GR. PL. CABLES = 277.134# ✓
d.) " " " COAX CABLES = 132.32# ✓
e.) " " " TEST ANTENNAS = 13.19# ✓
f.) " " " TEST ANT. COAXES = 50.22# ✓

798.834# → 798.834#

PARA 2.3.2.3 **WIND LOAD ON C'MAST ASS'Y @ 1" RAD. ICE.**

ON LIGHTNING ROD, 2.75 DIA × 103 = 283.25 in^2 = 1.967 ft^2 @ 19.8 psf (round) = 38.94# ✓
ON UPPER DISC 16.83 × 3" = 50.49 in^2 = .350 ft^2 @ 19.8 psf (–"–) = 6.94# } 9.00 ✓
ON UPPER FL. 12 × 1.25 = 15 in^2 = .104 ft^2 @ 19.8 psf (–"–) = 2.06# }
ON " MAST, TUBE 6.5 × (41.0 – 2) = 253.5 in^2 = 1.76 ft^2 @ 19.8 psf (–"–) = 34.85# } ✓
ON LOWER FL. 12 × 1.375 = 16.5 in^2 = .114 ft^2 @ 19.8 psf (–"–) = 2.26# }
@ AIRCRAFT W. LIGHTS 2 × 65 × 10 = 130 in^2 = .902 ft^2 @ 19.8 psf (–"–) = 17.875# ✓
@ OMNI ANTENNA (15.75 + 12) × 2.5 = 76.31 in^2 = .529 ft^2 @ 19.8 psf (–"–) = 10.492# } OMNI-ANT. 34.399# ✓
OMNI – LEGS 4 × 12.14 × 2.5 = 121.4 in^2 = .843 ft^2 @ 19.8 psf (–"–) = 16.69# }
OMNI – SUPPORT 4 × 2.187 × 5 = 43.74 in^2 = .303 ft^2 @ 23.76 psf (flat) = 7.217# }
@ INSULATORS 4 × 4 × 5 = 80 in^2 = .555 ft^2 @ 19.8 psf (round) = 11.00# ✓
@ GROUND PLANE DISC = 6.25 × 50 = 312.5 in^2 = 2.17 ft^2 @ 19.8 psf (round) = 42.96# ✓
@ SPACERS @ TOP OF LOWER MAST FL. = 12 × 1.875 = 22.5 in^2 = .156 ft^2 @ 19.8 psf (round) = 3.09# } 67.188 ✓
@ LOWER MAST 10.625 (86.5 – 1$\frac{7}{8}$ – 2 – 34.75 – 4.5) = 466.17 in^2 = 3.23 ft^2 @ 19.8 psf (round) = 64.098# }
@ LOWER SUSP. – SPINNING 42 × 6.5 = 273 in^2 = 1.89 ft^2 @ 19.8 psf (round) = 37.537# ✓
@ CONTROL BOX (FRONT, 1-ONLY) 26 × 34.25 = 890.5 in^2 = 6.18 ft^2 @ 28.28 psf (flat) = 174.88# } 257.92# ✓
@ CLIMBING STRUTS – 2 × 40 × 4 = 320 in^2 = 2.222 ft^2 @ 23.76 psf (flat) = 52.79# }
2 × 4 × 10 × 2.75 = 220 in^2 = 1.52 ft^2 @ 19.8 psf (round) = 30.25# }
@ LOWER MTG FL. #1 14 × 1.5 = 21 in^2 = .1458 ft^2 @ 19.8 psf (–"–) = 2.88# } 3.98# ✓
@ " " " #2 16 × 0.5 = 8 in^2 = .055 ft^2 @ 19.8 psf (–"–) = 1.1# }

C'MAST – HOR. WIND LOAD – SUBTOTAL = 557.909# ✓
HOR. WIND LOAD, C'MAST, DUE TO GUYS = 798.834#
TOTAL HOR. WIND LOAD ON C'MAST ASS'Y @ 1" RAD. ICE = 1356.743#

PARA 2.3.2.4 TOTAL WIND LOAD, ANTENNA ASS'Y @ 1" RAD. ICE.

WINDLOAD DUE TO ANNULAR RING ASS'Y, INCL. RED. SUSP. SYST.	2009.55#
" DUE TO C'MAST ASS'Y " " "	1356.743#
TOTAL HOR. WINDLOAD ΣΣ =	3366.293#

CALCULATION OF OVERTURNING MOMENT (FOR INFO SEE pp. #13 AND FIG. #4)

loc. OF WINDLOAD SAME AS SHOWN ON ABOVE REFERENCE:

WHERE $P_1'' = 38.94$#	@ LIGHT. ARR.	$l_1 = 178.675$ in	$M_1'' = P_1'' l_1 =$ 6957.60 in Lbs
$P_{2_1}'' = 236.69$#	@ UPPER SUSP.	$l_2 = 128.5$ in	$M_{2_1}'' = P_{2_1}'' l_2 =$ 30414.66 in Lbs
$P_{2_2}'' = 9.00$#	@ UPPER DISC	$l_2 = 128.5$ in	$M_{2_2}'' = P_{2_2}'' l_2 =$ 1156.50 in Lbs
$P_3'' = 37.11$#	@ UPPER MAST + FLANGES	$l_3 = 107.5$ in	$M_3'' = P_3'' l_3 =$ 3989.32 in Lbs
$P_4'' = 34.399$#	@ OMNI ANTENNA	$l_4 = 95.5$ in	$M_4'' = P_4'' l_4 =$ 3285.10 in Lbs
$P_{5_1}'' = 2009.55$#	@ ANNULAR RING ASS'Y	$l_5 = 86.5$ in	$M_{5_1}'' = P_{5_1}'' l_5 =$ 173826.07 in Lbs
$P_{5_2}'' = 544.699$#	@ DISC + MISC.	$l_5 = 86.5$ in	$M_{5_2}'' = P_{5_2}'' l_5 =$ 47116.46 in Lbs
$P_6'' = 57.188$#	@ FLANGES + UPPER SECT. LOWER MAST	$l_6 = 66.5$ in	$M_6'' = P_6'' l_6 =$ 3803.00 in Lbs
$P_{7_1}'' = 37.537$#	@ LOWER SUSP. SPRINGS	$l_7 = 48.0$ in	$M_{7_1}'' = P_{7_1}'' l_7 =$ 1801.776 in Lbs
$P_{7_2}'' = 92.28$#	@ LOWER SUSP.	$l_7 = 48.0$ in	$M_{7_2}'' = P_{7_2}'' l_7 =$ 4429.44 in Lbs
$P_8'' = 257.92$#	@ CBOXES + LADDER	$l_8 = 25.00$ in	$M_8'' = P_8'' l_8 =$ 6448.00 in Lbs
$P_9 = 10.00$#	@ LOWER MAST	$l_9 = 5.00$ in	$M_9'' = P_9'' l_9 =$ 50.00 in Lbs
$P_{10}'' = 2.98$#	@ LOWER FLANGES	$l_{10} = 0.50$ in	$M_{10}'' = P_{10}'' l_{10} =$ 1.49 in Lbs

[illegible] 277.134#
coax cables 132.32#
Test Ant. 13.19#
Test A. Coax 50.22#
472.864#

1/c W.L = 17.875#
insulator = 11.00#
GR. PL. DISC = 42.96#
71.835#
+ 472.864#
544.699#

$\Sigma P'' = P' = 3366.293$# ✓ TOTAL HOR. WINDLOAD

$\Sigma M =$ 283279.44 in Lbs
= 23606.62 ft Lbs = 23.6 K ft

LOADING CONDITIONS ON TOWER @ 1" RAD ICE + WINDS

$G_{\text{DEADWEIGHT ANT. ASS'Y}}$ = 1086.09#
1" RAD. ICE LOAD = 4590.406#
} COMBINED DW + 1" RAD ICE = 5676.428#

HORIZONTAL SHEAR @
TOWER INTERFACE = 3366.29#

OVERTURNING MOMENT
ABOUT POINT "O" = 23606.62 ft Lbs

PARA 2.4 - SUMMARY - LOADING CONDITIONS @ TOWER INTERFACE

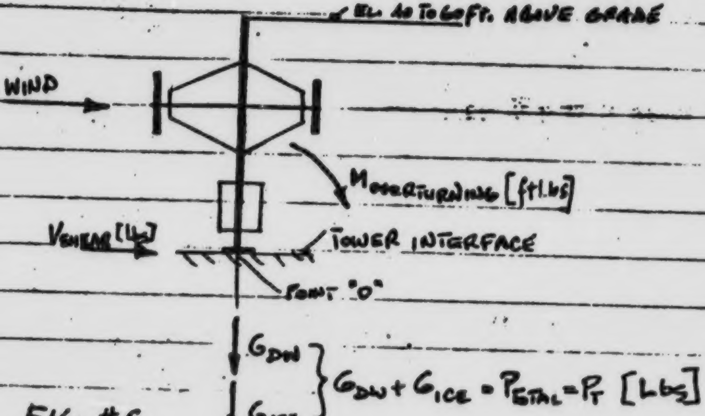

EL. 40 TO 60 FT. ABOVE GRADE
WIND
M OVERTURNING [ft Lbs]
V SHEAR [Lbs]
TOWER INTERFACE
POINT "O"
G DW
G ICE
$G_{DW} + G_{ICE} = P_{TOTAL} = P_T$ [Lbs]

FIG. #6

LOAD DESCRIPTION	WINDLOAD - NO ICE	WIND LOAD WITH 2" RAD. ICE	WIND LOAD WITH 1" RADIAL ICE
DEADWEIGHT - ANNULAR RING ASS'Y WITH SUSP.	537.52#	537.52#	537.52#
" - C'MAST ASS'Y WITH SUSP.	548.57#	548.57#	548.57#
ICE LOAD - ANNULAR RING ASS'Y WITH SUSP.	—	7792.87#	2611.57#
ICE LOAD - C'MAST ASS'Y WITH SUSP.	—	5238.62#	1978.83#
TOTAL DEADWEIGHT - ANT. ASS'Y	G_{DW} = 1086.09#	G_{DW} = 1086.09#	G_{DW} = 1086.09#
TOTAL ICE LOAD - ANT. ASS'Y.	—	G_{ICE} = 13031.49#	G_{ICE} = 4590.41#
DW + ICE - ANTENNA ASS'Y	—	P_T = 14117.58#	P_T = 5676.48#
WIND LOAD - ANNULAR RING ASS'Y WITH SUSP.	1625.33#	3458.79#	2009.55#
WIND LOAD - C'MAST ASS'Y	1003.32#	2262.707#	1356.74#
TOTAL HOR. WIND LOAD	V_{SH} = 2628.65#	V_{SH} = 5721.49#	V_{SH} = 3366.29#
OVERTURNING MOMENT DUE TO WIND	M = 16870.83 ft Lbs	M = 40833.03 ft Lbs	M = 23606.62 ft Lbs

PARA 3.0 – ANTENNA STRESS ANALYSIS.

DETAILED STRESS ANALYSIS SHALL BE MADE TO EVALUATE STRESS LEVELS, SAFETY FACTORS, DEFLECTION, PRELOAD LEVELS OF SUSPENSION UNDER THE SPECIFIED ENVIRONMENTAL CONDITIONS.

PARA 3.1 ANNULAR RING AND SUSPENSION SYSTEM LOAD STRESS AND DEFLECTION ANALYSIS.

CALCULATING THE UPPER/LOWER STRUT TENSION IN THE ANNULAR RING ASS'Y AND THE GRAVITY CAUSED TENSION AND TORSION IN THE NONMETALIC SQ. TUBING – ANNULAR RING ASS'Y.

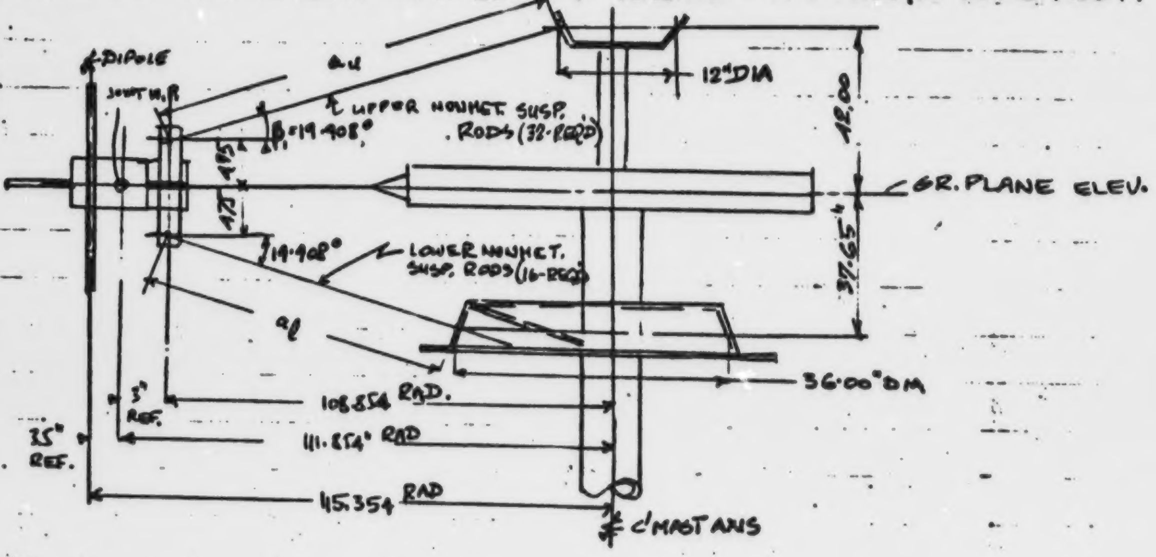

DIPOLE
JOINT H.R
a_u
℄ UPPER NONMET. SUSP. RODS (32-REQ'D)
β=19.408°
4.75
4.75
12"DIA
12.00
GR. PLANE ELEV.
37.65"
19.408°
LOWER NONMET. SUSP. RODS (16-REQ'D)
a_ℓ
36.00" DIA
3" REF.
108.854 RAD.
111.854" RAD
35" REF.
115.354 RAD
℄ MAST AXIS

FIGURE # 7

ELEVATION VIEW – ANNULAR RING ASS'Y, WITH SUSPENSION SYSTEM.

$$a_u = \sqrt{(42 - 4.75)^2 + (108.854 - 6)^2} = 109.39"$$

$$a_\ell = \sqrt{(\text{[illegible]}.65 - 4.75)^2 + (108.854 - 12)^2} = 96.62"$$

LOADTRANSFER, SUPPORT SYSTEM:

@ NO ICE CASE, WEIGHT OF ANNULAR RING ASS'Y, INCL. SUSP. = 537.52#

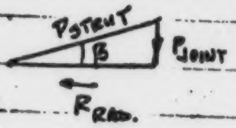
@ 1" RAD. ICE, DW + ICE LOAD ON ANNULARRING ASSY = 3149.09#

@ 2" RAD. ICE, —"— —"— —"— —"— = 8330.59#

PARA 3.1 CONT'D.

a) SIZING OF UPPER NONMETALIC STRUTS

WEIGHT SUPPORTED BY UPPER STRUTS – NO ICE CASE



@ $\beta_1 = 19.908°$

$P_{JOINT} = \frac{537.52\#}{32} = 16.64\#$, WHERE ANNULAR RING DW = 537.52# WHICH DOES NOT INCL. EXTRA DOWNWARD LOAD DUE TO LOWER STRUT PRETENSION

a.a FOR EQUILIBRUM – DEADLOAD ONLY

$\frac{P_{JOINT}}{P_{STRUT}} = \sin 19.908$; $P_{STRUT} = \frac{P_{JOINT}}{\sin\beta_1} = \frac{16.64}{0.3405} = 48.86\#$

THE RADIAL LOAD IN THIS CASE $P_{RAD} = \frac{P_{JOINT}}{\tan\beta_1} = \frac{16.64}{.3621} = 45.947\#$

a.b.) IN THE CASE OF DW + 2" RAD ICE, WITH ANNULAR RING ASSY, DW + ICE = 8330.39#

$P'_{JOINT} = \frac{8330.39}{32} = 260.32\#$

$P'_{STRUT} = \frac{P'_{JOINT}}{\sin\beta_1} = \frac{260.32}{.3405} = 764.52\#$

RADIAL LOAD = $P'_{RAD} = \frac{P'_{JOINT}}{\tan\beta_1} = \frac{260.32}{.3621} = 718.917$

a.c) IN THE CASE OF DW + 1" RAD ICE, WITH ANNULAR RING ASSY, DW + ICE = 3149.09#

$P''_{JOINT} = \frac{3149.09}{32} = 98.409\#$

$P''_{STRUT} = \frac{P''_{JOINT}}{\sin\beta_1} = \frac{98.409}{.3405} = 289.013\#$

RADIAL LOAD, $P''_{RAD} = \frac{P''_{JOINT}}{\tan\beta_1} = \frac{98.409}{.3621} = 271.77\#$

b) SIZING UPPER SUSPENSION SYSTEM AND PRELOAD LEVEL:

EXTREME ROD – NOMINAL TENSILE STRENGTH, AS GIVEN = 100000 psi

USING .25" DIA, BREAKING STRENGTH FOR

$\sigma = \frac{P_{BREAK}}{F} = 100{,}000 = \frac{P_{BREAK}}{\frac{.25^2\pi}{4}} = \frac{P_{BR}}{.049}$; $P_{BR} = \underline{4908.73\#}$

TENSILE BREAKING TESTS CONDUCTED BY ONTARIO RESEARCH FDN. SHOWED THAT ROD FRACTURED @ 4360# to 4775# OR 11% BELOW BOOK VALUE.

PARA 3.1 CONT'D.

HOWEVER, THESE TESTS ALSO SHOWED, THAT MOST TEST SAMPLES FAILED BELOW THE TENSILE STRENGTH OF THE ROD AT THE ROD TO FITTING JOINT.

SAMPLES TESTED WITH EPOXY, IDENTIFIED AS SERIES 555 (WHICH WILL BE USED) SHOWED FAILURE IN THIS JOINT AT

SAMPLE №	MAX. LOAD LBS
555-1	2500
-2	3480
-3	2640
-4	2760
-5	4360

MIN = 2500#
MAX = 4360#
AVE = 3148#
BREAKING STRENGTH

SINCE THE UPPER RODS SHALL BE 3/8 DIA, INSTEAD OF 1/4 DIA, AND THE JOINT STRENGTH IS DIRECTLY PROPORTIONAL TO THE "OVERALL WETTED AREA" @ THE EPOXIED JOINT, THUS THE MIN./MAX AND AVE JOINT STRENGT IS DIRECTLY PROPORTIONAL WITH

$$\frac{\frac{3}{8}}{\frac{1}{4}} = 1.5,$$ ASSUMING SAME JOINT LENGTH (WHICH IS THE CASE HERE)

THUS MIN. JOINT BREAKING STRENGTH = 2500 × 1.5 = 3750#
MAX. " " " = 4360 × 1.5 = 6540#
AVE " " " = 3148 × 1.5 = 4722#

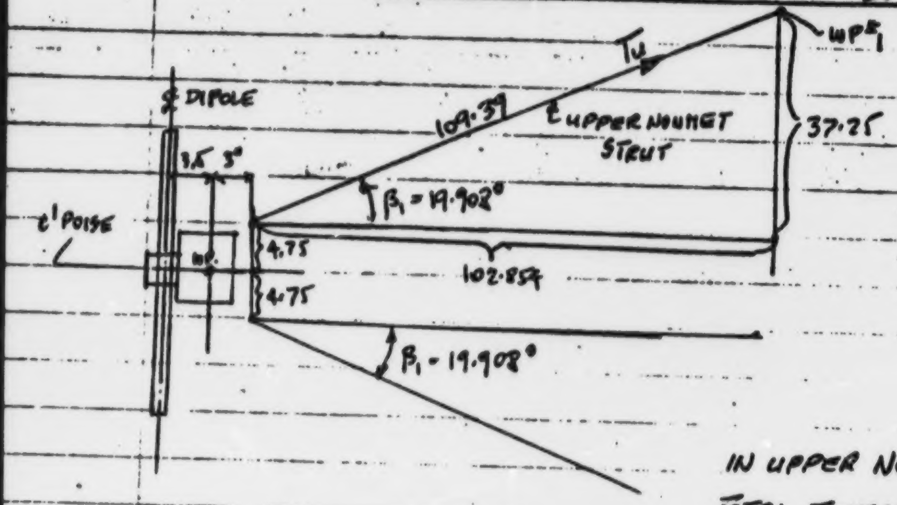
BREAKING STRENGTH – ROD, $P_{3/8} = 100{,}000 \times \frac{.375^2\pi}{4} = 11044.66$# NOM.

OR 11% low, 11044.66
− 1214.91 (11%)
9829.75# (PREDICTED)

SINCE THE ADHESIVE JOINT @ THE FITTINGS ARE APPR. only 50% IN STRENGTH OF THE ROD STRENGTH, IN THE ANALYSIS ONLY THE JOINT STRENGTH SHALL BE CONSIDERED.

PARA 3.1 CONT'D

PARA 3.1.1 SELECTION OF UPPER NONMETALIC SUSPENSION SYSTEM – PRELOAD AND SPRING SELECTION.



WP#1
T_U
℄ DIPOLE
109.39
℄ UPPER NONMET STRUT
37.25
3.5
3"
$\beta_1 = 19.902°$
℄ POISE
W.P.
4.75
4.75
102.859
$\beta_1 = 19.908°$

FIG. #8

IN UPPER NONMETALIC STRUT

TOTAL TENSION = $P_{PRELOAD}$

$$= (DW+ICE)_{3"RAD} + \underline{764.52^{\#}}$$

$$P_{PREL.} + 764.52^{\#} = T_{U_{MAX}}$$

@ DW ONLY $T_{U_{DW}} = 48.86 + P_{PREL.}$

SELECTED PRELOAD $100^{\#}$ TO $120^{\#}$ RANGE – UPPER NONMET. SUSP. SYSTEM (say $110^{\#}$

THUS @ DW. ONLY $T_{U_{DW}} = 48.86 + 110.00 = 148.86^{\#}$ $TENSION_{MIN}$

@ DW + 3" RAD. ICE $T_{U_{DW+ICE}} = 764.52 + 110.00 = 774.52^{\#}$ $TENSION_{MAX}$

CORRESPONDING TENSILE STRESS – UPPER SUSPENSION

ROD DIA = .375 IN

$$A = \frac{d^2\pi}{4} = \frac{.375^2\pi}{4} = .110 \text{ in}^2$$

$$\sigma_1 = \frac{T_{U DW}}{A} = \frac{148.86}{.110} = 1347.8 \text{ psi}$$

$$\sigma_2 = \frac{T_{U DW+ICE}}{A} = \frac{774.52}{.110} = 7012.6 \text{ psi}$$

USING $100000-(1-.11) = 89000$ psi max breaking strength

$$FS_1 = \frac{89000}{1347.8} = 66 >> 4.00 \text{ OK}$$

$$F_{S_2} = \frac{89000}{7012.6} = 12.69 >> 4.00 \text{ OK}$$

@ JOINTS, FACTOR OF SAFETY

$$FS_{j_1} = \frac{3750^{\#}}{148.86^{\#}} = 25.19 >> 4.00 \text{ OK}$$

$$F.S._{j_2} = \frac{3750}{774.52} = 4.84 > 4.00 \text{ OK}$$

PARA 3.1.1 CONT'D.

TWISTING MOMENT CAUSED EFFECTS @ WP. (MOMENT TO WP.)

2" ICE + DW. @ C'POISE = 10.41 + .318 = 10.728# @ l_{CP} = 8.78 + 3.5 = 12.28" ARM

@ DIPOLE = 2.747# + 30.2# = 32.947# @ l_{DP} = 3.5" = 3.5" -"-

@ REAR STR. = 14.06# = 14.06# @ l_{RS} = 3.0" -"-

ASSUMED 32 CONN. INST. OF 16, SQ. TUBE TO TRANSM. LOAD IN BETW.

* @ REAR STR. LOWER SUSP'N + MISC = $\frac{3337.316-1007.68}{32}$ = 72.801# @ l_{RS} = 3.0" "

@ UPPER STR. $\frac{1007.68}{32}$ = 31.49# @ l_{RS} = 3.0" "

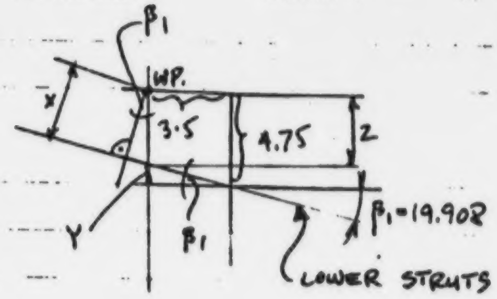
MOMENT ABOUT WP. (JOINT @ 3" SQ. NONMET. TUBING)

$$M_{TORSION} = 10.728 \times 12.28 + 32.947 \times 3.5 - (14.06 + 72.801 + 31.49) \times 3 =$$

$$= 247.054 - 355.053 = -107.99 \text{ in lbs}$$

DIRECTION $\left. -M_T \right)$

THUS LOWER STRUTS ARE LOADED WITH THIS MOMENT ONLY



ARM "X" = 3.274 in

ΔTension @ 2" RAD ICE + DW - LOWER SUSPENSION = $2 \times \frac{-M_T}{X} = -2 \cdot \frac{107.99}{3.274} = 66.51\#$ PER SUSP.

$\frac{Y}{3.5} = \tan \beta_1$ | $Y = 1.2675$ in

$Z = 4.75 - Y = 3.48$ in

$X = \cos \beta_1 \times Z = 3.274$ in

EXTENSION OF UPPER SUSPENSION LINKAGE UNDER LOAD

DUE TO DEADWEIGHT $\Delta_{DW} = \frac{P_{DW} \times l_{EFF}}{A \times E} = \frac{48.86 \times 102.39}{.110 \times 0.8 \times 10^6} = 0.0568$ in

where l_{eff} = 109.39 - 7 = 102.39" (length of rod)

A = .110 in² ROD AREA

E = 0.8 × 10⁶ psi TENSION MODULUS

EXTENSION OF UPPER SUSPENSION LINKAGE DUE TO PRELOAD

$$\Delta_{PRELOAD} = \frac{P_{REL.} \times l_{EFF}}{AE} = \frac{110 \times 102.39}{.110 \times 0.8 \times 10^6} = .127 \text{ in}$$

PARA 3.1.1 CONT'D

EXTENSION - UPPER SUSPENSION RODS, UNDER 2" RAD. ICE

$$T_{TENS,\,ICE} = 764.52 - 48.86 = 715.66^{\#}.$$

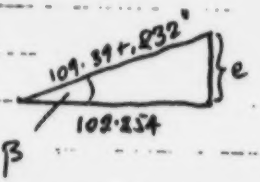
$$\Delta_{2"RAD\,ICE} = \frac{T_{TENS} \times l_{eff.}}{A \times E} = \frac{715.66 \times 102.39}{.110 \times 0.8 \times 10^6} = \underline{\underline{0.832"}}$$

EFFECTS OF Δ_{DW}, $\Delta_{PREL.}$ AND $\Delta_{2"RAD}$ ICE ON STRUCTURE.

THE $\Delta_{DW} + \Delta_{PREL} = .0562" + .127" = .183"$ IS AUTOMATICALLY COMPENSATED @ ASS'Y WITH THREADED FITTING.

EFFECT OF $\Delta_{2"ICE} = .832"$ EXTENSION OF UPPER SUSPENSION LINK WOULD LOWER THE ANNULAR RING ASS'Y TO

$e_{NOM} = 37.25"$



$e_{EXT} = 39.622"$

$t'_{ICE} = e_{EXT} - e_{NOM} = 2.372$ in (SINKING DUE TO EXTRA LOAD)

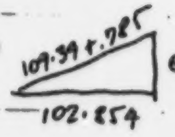
HOWEVER, DURING SINKING β, THE INCL. ANGLE WILL INCREASE, THUS THE TENSION IN UPPER ROD WILL DECREASE. CONSEQUENTLY THE EQUILIBRUM WILL BE REACHED AT A LOWER THAN $t'_{ICE} = 2.372$ in

$\tan \beta_{MOD} = \frac{e_{ext.}}{102.854} = 0.3852$; $\beta_{MOD} = 21.06°$

$T_{TENS_{MOD}} = \frac{243.58}{\sin \beta_{MOD}} = 632.304^{\#}$; THUS $\Delta'_{2\,RAD\,ICE} = \frac{T_{TENS\,MOD.} \times l_{eff}}{AE} = \frac{632.3 \times 102.39}{.110 \times 0.8 \times 10^6}$

$= .785$ in (inst of .832")

SO



$e_{MOD} = 39.49$

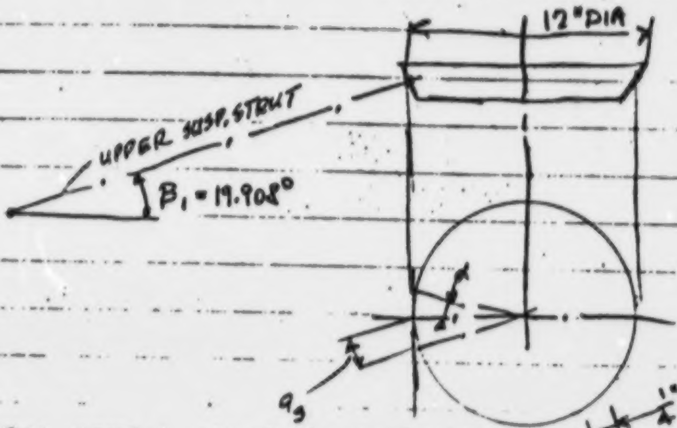
$t''_{ICE} = 39.49" - 37.25" = 2.24$ in

THUS THE MOVEMENT OF THE ANNULAR RING ASS'Y DOWNWARD WILL BE BETWEEN $t'_{ICE} = 2.372"$ AND $t''_{ICE} = 2.24"$

COMPENSATION WILL BE REQUIRED @ THE LOWER SUSPENSION SYSTEM TO COUNTERACT (STILL RETAIN TENSION IN RODS) AFTER THIS MOVEMENT TAKE PLACE.

PARA 3.1.1 CONT'D.

SELECTION OF SPRINGS - TENSIONING UPPER SUSP. SYSTEM:


12"DIA
UPPER SUSP. STRUT
$B_1 = 19.908°$
a_s

DISTANCE BETWEEN STRUTS @ $\alpha = \frac{360}{32} = 11.25°$ DIVISIONS

$a_s = 2 \times 6 \times \sin\frac{\alpha}{2} = 1.176''$

CROSS SECTION UPPER SUPPORT DISH:

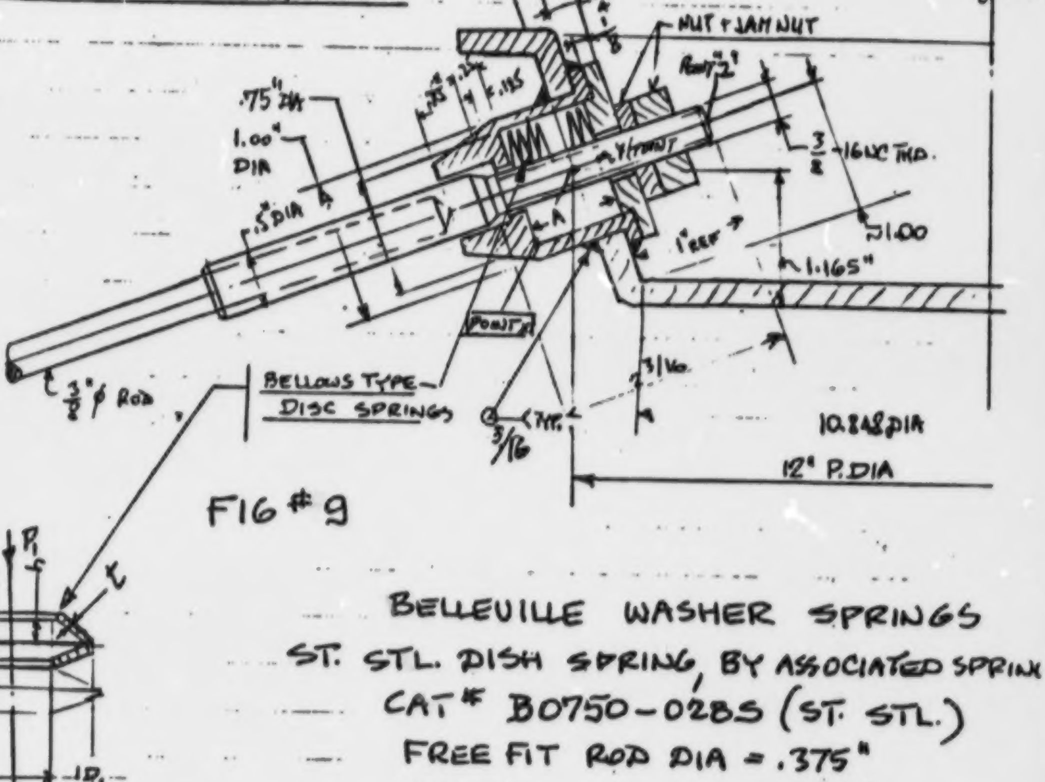
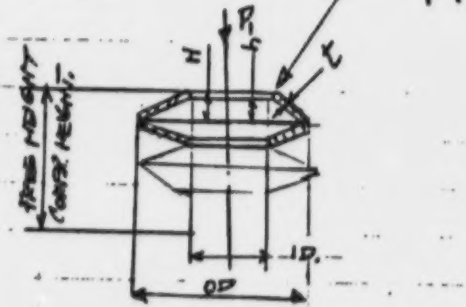

1/4" TH. OR 3/8 TH AL. SPINNING
1/4
1/8
℄ MAST
NUT + JAM NUT
.75" DIA
1.00" DIA
.5 DIA
.135
.224
.185
POINT 2
Y POINT
A
3/8 -16UNC THD.
1.00
1" REF
1.165"
POINT A
℄ 3/8" φ ROD
BELLOWS TYPE DISC SPRINGS
3/16 (TYP.)
3/16
10.848 DIA
12" P.DIA

FIG #9


H
P_1
f
t
FREE HEIGHT
(COMPR. HEIGHT)
I.D.
OD

BELLEVILLE WASHER SPRIN STACKED COMBINATION.

FIG #10

BELLEVILLE WASHER SPRINGS

ST. STL. DISH SPRING, BY ASSOCIATED SPRING

CAT # B0750-028S (ST. STL.)

FREE FIT ROD DIA = .375"

MIN. ID = .380"

MAX OD = .750"

FREE FIT, HOLE DIA = .750"

t = .0280"

H (APPR.) FREE, = .051"

H_1 (COMPRESSED @ LOAD) = .039"

P_1 (LOAD) = 93 TO 127#

P_{FLAT} (MAX LOAD) = 175#

PARA 3.1.1 CONT'D.

DIM "A" – LENGTH OF SPRING, PRELOAD @ $P_1 = \frac{93+127}{2} = 110^{\#}$ AVE.

DESIRED COMPR. CAVITY LENGTH ≥ .875 in

PAIR OF DISC SPRING HEIGHT UNDER COMPRESSED COND @ $P_1 = 110^{\#}$

$2H_1 = 2 \times .039 = .078$ in/pair

@ .875 in compressed height, number of pairs $= n = \frac{.875}{.078} = 11.21$ say 11

$11 \times .078 = .858"$ is compressed height = "A"

Free Height = $11 \times 2 \times .051 = 1.122"$

DEFL. UNDER PRELOAD = $1.122 - .858 = .264"$ OK.

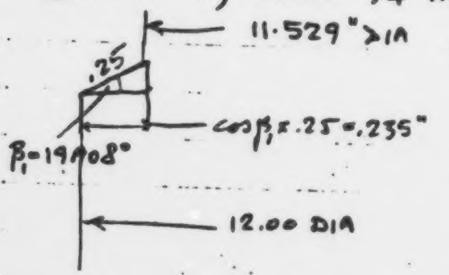
TOTAL # OF DISCS REQ'D –

$11 \times 2 \times 32 = 704$ DISC REQ'D @ UPPER STRUT @ 22/STRUT

CLEARANCE BETWEEN INDIVIDUAL SPRING RETAINER CUPS:

@ POINT "X", DIST. BETWEEN OUTER CIRC. $= a_{S_1} = 1.176$, with .176" left for welding (min)

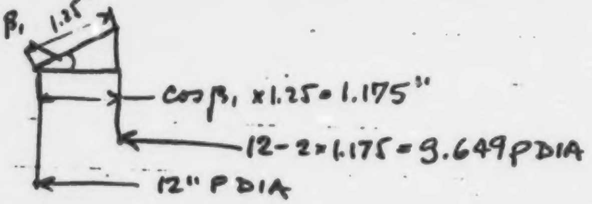
@ POINT "Y", USING 1/4"TH SPINNING, DIST.



DIST. BETW. ADJACENT POINTS Y_1 where $\frac{\alpha}{2} = \frac{360}{2\times32} = \frac{[illegible]}{2}$

$\overline{Y_1Y_2} = 11.529 \times \sin\frac{\alpha}{2} = 1.130$ in OK.

@ POINT "Z", DIST. BETW. FITTINGS

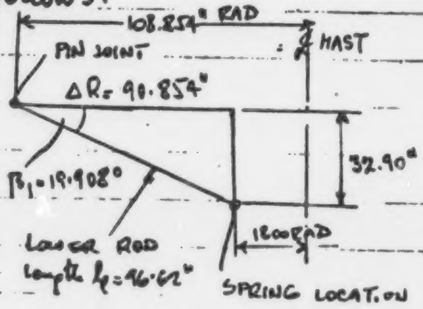


DIST. BETW. ADJACENT POINTS

$\overline{Z_1Z_2} = 9.649 \times \sin\frac{\alpha}{2} = .945"$ OK

PARA 3.1.2 LOWER SUSPENSION SYSTEM SELECTION.

THE SUSPENSION SYSTEM (LOWER) IS 1/4" DIA NONMET. RODS
NUMBER OF RODS: 16-REQ'D (EVERY SECOND JOINT IS CONNECTED)
THE SPRING PRELOAD IS TO BE DETERMINED CONSIDERING "RELAXATION" OF THE ANNULAR RING UNDER ICE LOAD. EFFECTS OF DOWNWARD MOVEMENT OF ANNULAR RING ON LOWER SUSPENSION SYSTEM RODS ARE AS FOLLOWS:

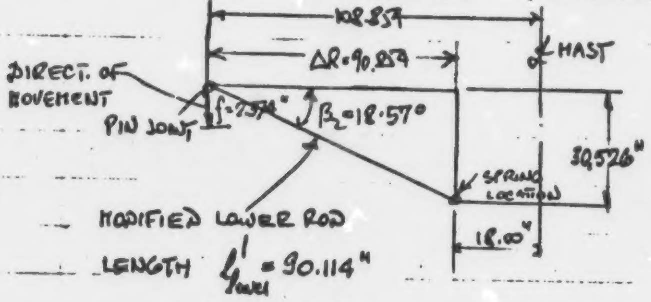

108.854" RAD
MAST
PIN JOINT
ΔR=90.854"
32.90"
β1=19.908°
18.00 RAD
LOWER ROD
Length l1=96.62"
SPRING LOCATION

where $\Delta R = 108.854 - 18 = 90.854"$

NOMINAL GEOMETRY WITHOUT "RELAXATION"

FIG #11 a

WITH A DOWNWARD MOVEMENT OF $f = \underline{2.24"}$, THE GEOMETRY WILL CHANGE AS FOLLOWS: (FOR CALC. OF $f = 2.24$, see pg. 38)


108.857
ΔR=90.854
MAST
DIRECT. OF MOVEMENT
PIN JOINT
f=.7394"
β2=18.57°
30.526"
SPRING LOCATION
18.00"
MODIFIED LOWER ROD
LENGTH l'lower=90.114"

Change in length due to downward move "f"

$$\Delta l_{lower} = 96.62 - \sqrt{90.854^2 + (32.9 - 2.24)^2} = .7395"$$

say $\underline{.74}"$

$$\tan \beta_2 = \frac{30.526}{90.854} = .33598 ; \beta_2 = \underline{18.57^\circ}$$

GEOMETRY - AFTER RELAXATION

FIG #11 b

SELECTION OF SPRING - LOWER SUSPENSION SYSTEM.

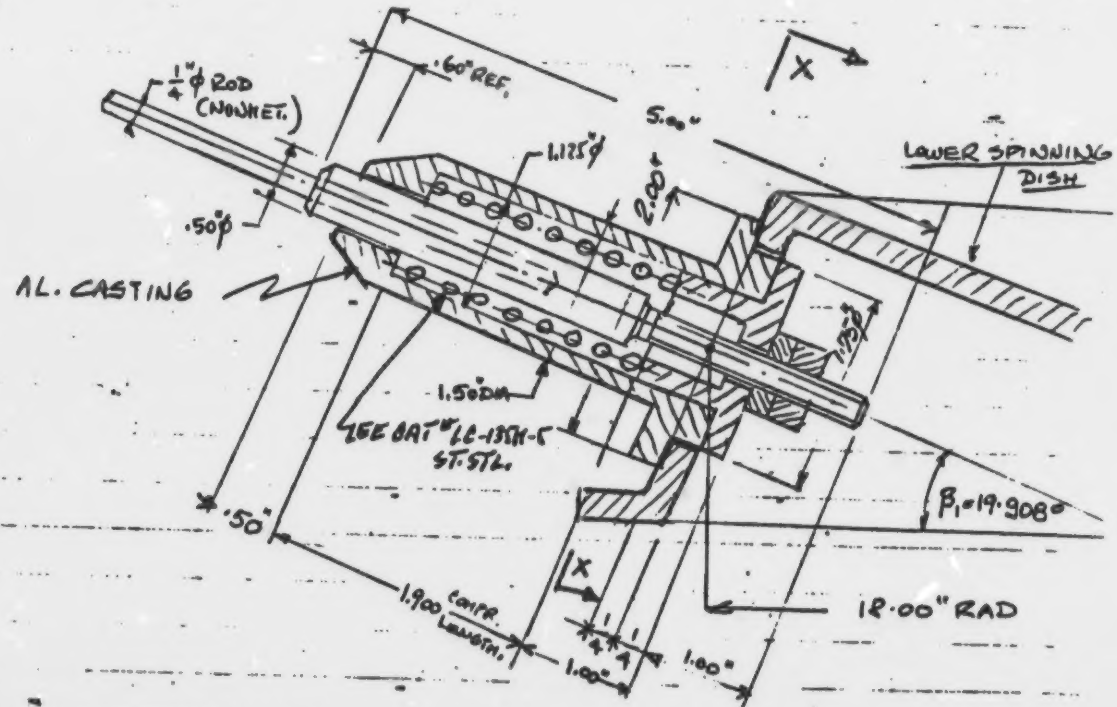
SPRING SELECTION IS MADE, SO A "LONG STROKE" IS SELECTED, WHERE, AFTER A .74" MOVEMENT ALONG THE AXIS OF THE LOWER SUSPENSION STRUT THERE IS STILL ADAQUATE PRELOAD REMAINING IN THE SPRING SYSTEM.

PARA 3.1.2 CONT'D.

SELECTED SPRING - LOWER STRUT
LEE CAT # LC-135M-5, STAINLESS STEEL, WITH THE FOLLOWING CHARACTERISTICS:

MATERIAL	ST. STL
OUTSIDE DIA	1.095 IN
HOLE DIA	1.125 IN
WIRE DIA	.135 IN
APPR. LOAD@SOLID HEIGHT	= 100 #
FREE LENGTH	= 3.50 IN
SPRING RATE	= 53 #/IN
SOLID HEIGHT	= 1.665 IN
MAX. STROKE	= 1.835 IN

NOTE:
ABOVE SPRING RATE AND LOAD@ SOLID HEIGHT IS GIVEN FOR PIANO WIRE ONLY.
FOR ST. STL. DERATE VALUES BY $\frac{5}{6}$ = .833

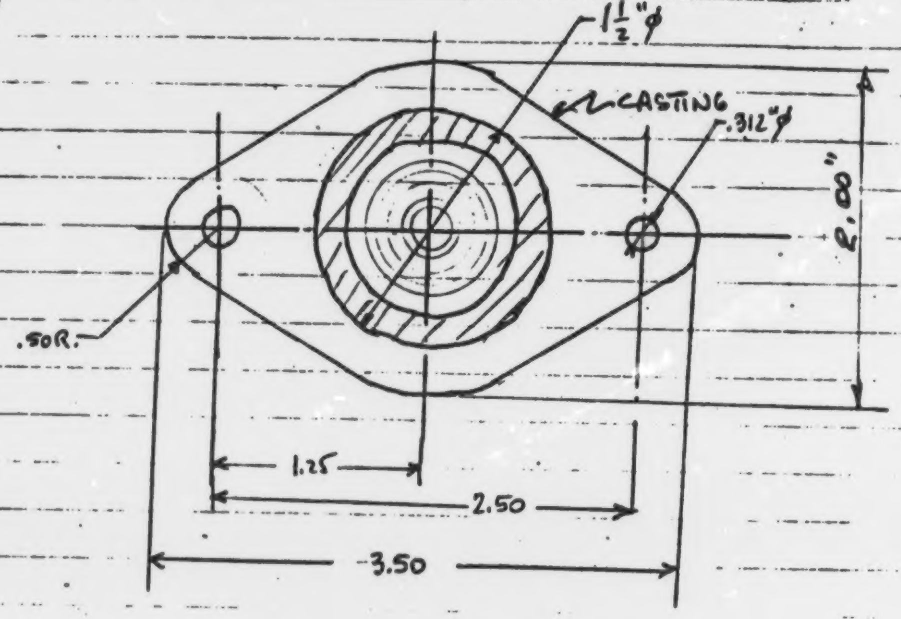


$\frac{1}{4}$" ϕ ROD (NONMET.)
.60" REF.
X
5.00"
1.125 ϕ
2.00"
LOWER SPINNING DISH
.50 ϕ
AL. CASTING
1.75"
1.50" DIA
LEE CAT # LC-135M-5 ST. STL.
.50"
β₁ = 19.908°
X
1.900 COMPR. LENGTH.
1/4
1/4
1.00"
1.00"
12.00" RAD

FIG # 12a

CROSS SECTION - LOWER STRUT
PRELOAD SPRING ASS'Y

PARA 3.1.2 CONT'D



SECTION X-X
(SEE FIG #12a)

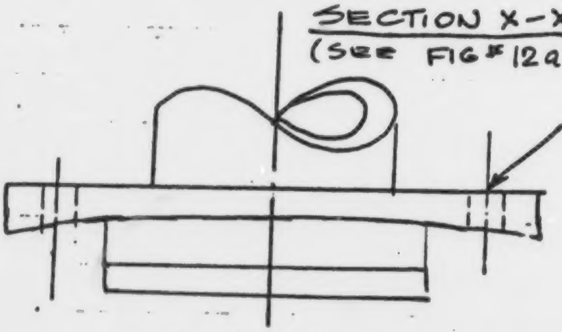


FIG # 12 b

THESE TWO BOLTS ARE USED TO MOUNT SPRING RETAINER HOUSING TO LOWER SPINING. BY SELECTING LONGER BOLTS (BY $1\frac{1}{2}$") SPRING TENSIONING RANGE OF 3.5-1.9 = 2.3 IN IS ACHEAVED

ADJUSTM. @ FITTING	1"
ADJUST. ON AUX. BOLTS	1.75
TOTAL ADJ. ACHEAVED:	2.75
ADJ. REQ'D	2.3
MARGIN	0.45"
	OK

LOWER SUSPENSION SYSTEM - TENSIONING REQUIREMENTS

FROM MOMENT (SEE PP 33) TRANFER, TENSION = 66.51#/STRUT

PRELOAD TENSION, NOMINAL VALUE

@ 1.900" SPRING COMPRESSED HEIGHT

$$P'_{sp} = (3.5-1.9) \times 53 \times \frac{5}{6} = 70.66^{\#}$$

$$P_{sp_1} = \text{TOTAL TENS.} = 137.17^{\#}$$

AFTER "RELAXATION" OF STRUCTURE,

BALANE OF SPRING LOAD REMAINING

$$P''_{sp} = 3.5-(1.9+.74) \times 53 \times \frac{5}{6} = 37.98^{\#}$$

TENSION IN ROD = 66.51# + 37.98# = 104.49# @ RELAXATION

PARA 3.1.2 CONT'D.

IF $P'_{SP} = 137.17^{\#}$ (MAX), THE CORRESPONDING TENSILE STRESS @ 1/4" ϕ EXTRENE ROD IS

$\sigma_T = \frac{P}{F} = \frac{137.17}{.049} \cong 2800 \text{psi}$ where $F = \frac{.25^2 \pi}{4} = .049 \text{in}^2$

MINIMUM TENSILE, MEASURED 2500#

$F.S = \frac{89000}{2800} = 31{,}78 \gg 4.0$ RECOMMENDED

@ ADHESIVE JOINT, MINIMUM TENSION @ FAILURE WAS 2500#

$F.S. = \frac{2500}{137.17} = 18.22 \gg 4.0$ RECOMMENDED.

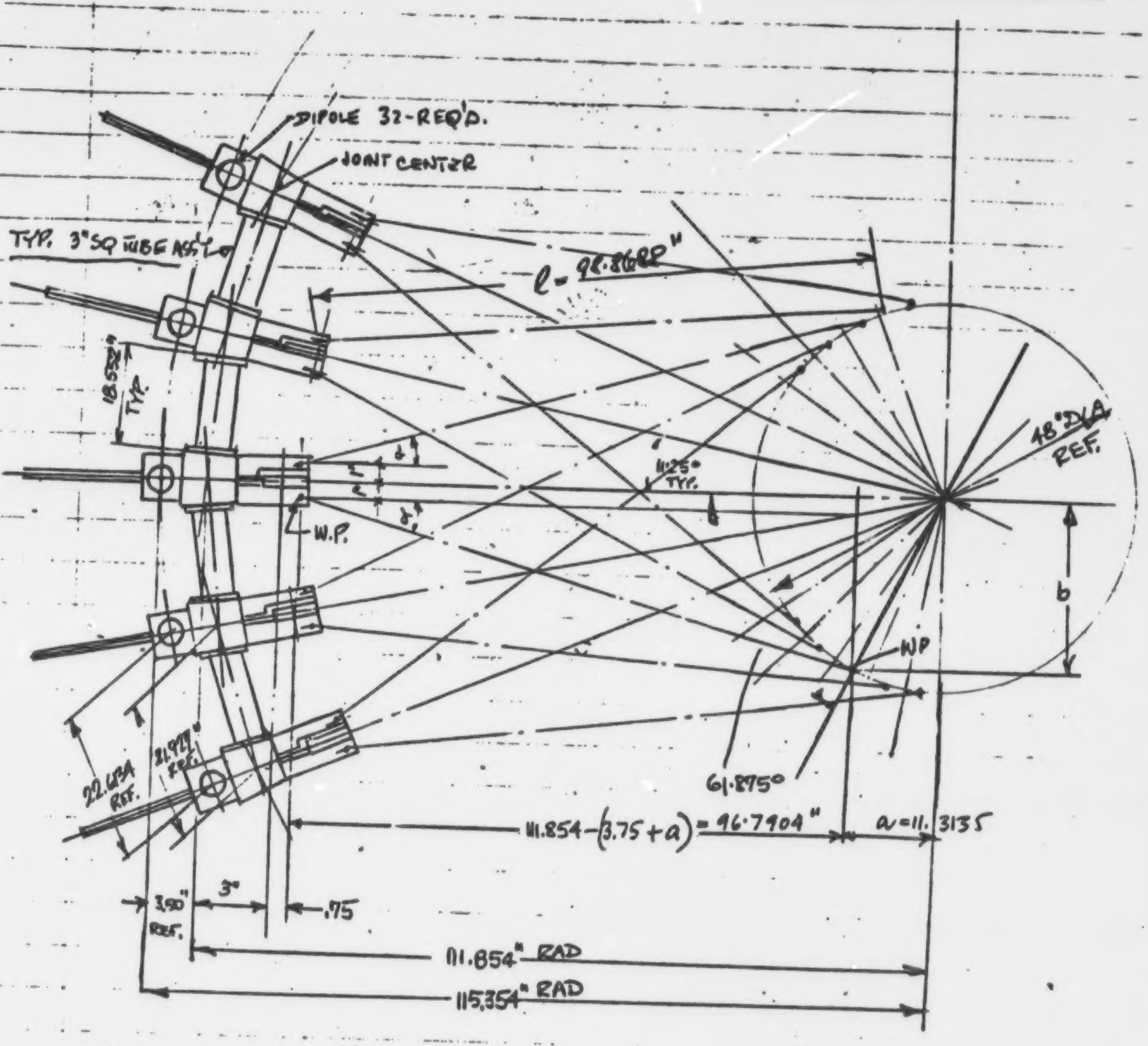
EXTENSION – LOWER SUSP. ROD UNDER TENSION.
WHERE EFF. LENGTH $= l_{eff} = 96.62 - (5 - 1.75) = 89.37"$

$\Delta'_{load_L} = \frac{P_{MAX}\, l_{eff}}{A_{\frac{1}{4}} \times E} = \frac{137.17 \times 89.37}{.049 \times 0.8 \times 10^6} = .312"$ at nominal setting the pretension value for the spring is automatically adjusted for.

AT RELAXED CONDITIONS, EXTENSION DUE TO PRETENSION + MOMENT BALANCE

$\Delta'_{load_L} = \frac{P\, l_{eff}}{A_{\frac{1}{4}}\, E} = \frac{104.49 \times 89.37}{0.049 \times 0.8 \times 10^6} = 0.237"$

PARA. 3.1.3 GROUND PLANE CABLE SUSPENSION SYSTEM.


DIPOLE 32-REQ'D.
JOINT CENTER
TYP. 3" SQ TUBE ASS'Y
$l = 98.8688"$
18.552" TYP.
δ
11.25° TYP.
W.P.
48" DIA REF.
b
WP
22.634 REF.
21.927" REF.
61.875°
$111.854-(3.75+a)=96.7904"$
$a=11.3135$
3.90" REF.
3"
.75
111.854" RAD
115.354" RAD

where $a = \cos 61.825° \times 24 = 11.3135"$

$b = \sin 61.825° \times 24 = 21.1661"$

$l = \sqrt{a^2-(b-1)^2} = 98.8688"$

$\tan\alpha = \dfrac{30.1661}{46.7904} = 0.208348$; $\underline{\underline{\alpha = 11.768°}}$

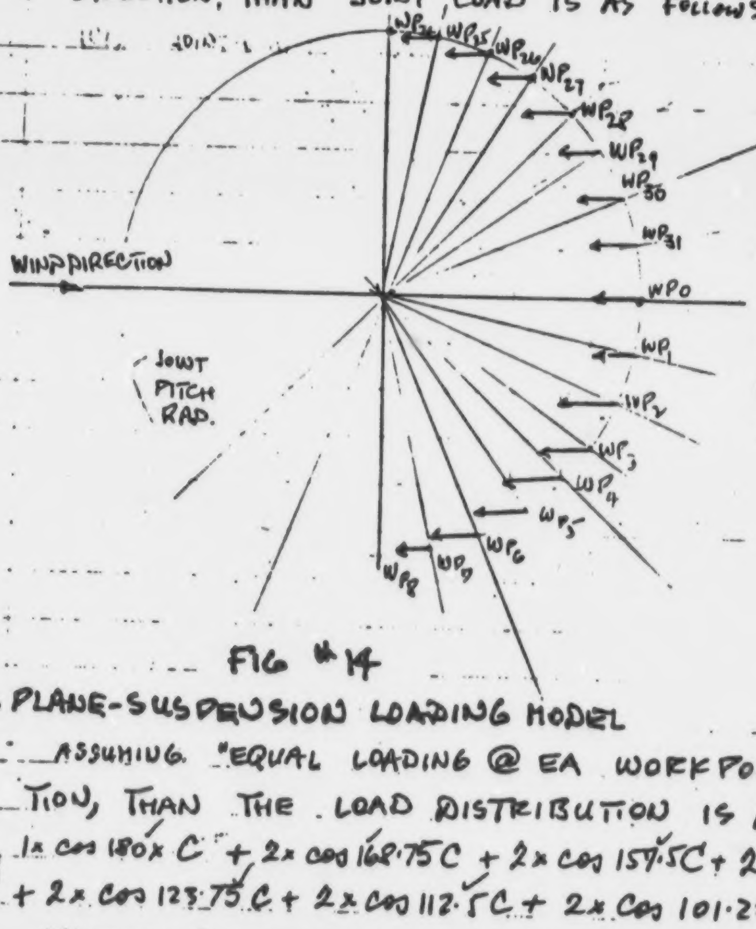
FIG #13
ANNULAR RING - CABLE SUPPORT GEOMETRY

3.1.8.1 TENSIONING REQUIREMENTS - GR. PL. ST. STL. CABLES

WINDLOAD @ 2" RAD ICE + WIND - WORST CASE CONSIDERATIONS.
TOTAL HORIZONTAL WINDLOAD - ANNULAR RING ASS'Y,
INCLUDING SUSPENSION SYSTEM = 3458.79# (SEE pp 21)

ASSUMING, THAT ONLY CABLES IN TENSION ARE ACTIVE ($\frac{1}{2}$ sector of ring) AND EACH PAIR OF CABLE SHARE ITS LOAD PROPORTIONALLY, THAN

IF JOINT # 0 IS ASSIGNED TO JOINT DIAGONALLY OPPOSITE TO WIND DIRECTION, THAN JOINT LOAD IS AS FOLLOWS



@ WP_0 ANGLE TOWARDS WIND - 180°
@ $WP_1^{\#}$ AND $WP_{31}^{\#}$ " " 180-11.25=168.75°
@ $WP_2^{\#}$ AND $WP_{30}^{\#}$ " " 180-2×11.25=157.50°
@ $WP_3^{\#}$ AND $WP_{29}^{\#}$ " " 180-3×11.25=146.25°
@ $WP_4^{\#}$ AND $WP_{28}^{\#}$ " " 180-4×11.25=135.00°
@ $WP_5^{\#}$ AND $WP_{27}^{\#}$ " " 180-5×11.25=123.75°
@ $WP_6^{\#}$ AND $WP_{26}^{\#}$ " " 180-6×11.25=112.5°
@ $WP_7^{\#}$ AND $WP_{25}^{\#}$ " " 180-7×11.25=101.25°
@ $WP_8^{\#}$ AND $WP_{24}^{\#}$ " " 180-8×11.25=90°

FIG # 14
GR. PLANE-SUSPENSION LOADING MODEL

ASSUMING "EQUAL LOADING @ EA WORKPOINT TOWARDS WIND DIRECTION, THAN THE LOAD DISTRIBUTION IS AS FOLLOWS

$$1 \times \cos 180 \times C + 2 \times \cos 168.75 C + 2 \times \cos 157.5 C + 2 \times \cos 146.25 C + 2 \times \cos 135 C +$$
$$+ 2 \times \cos 123.75 C + 2 \times \cos 112.5 C + 2 \times \cos 101.25 C = P_W = 3458.79\#$$

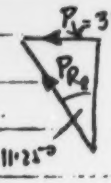
WHERE C = JOINT LOAD - TOWARDS WIND,

$$1 \times -1C + 2 \times -.9807C + 2 \times -.923879C + 2 \times -.83146C + 2 \times -.707C + 2 \times -.555C +$$
$$+ 2 \times -.3826C + 2 \times -.195C = -10.1512C = 3458.79\#$$

$$C = -\frac{P_W}{10.1512} = -340.724\#$$

PARA 3.1.3.1 CONT'D

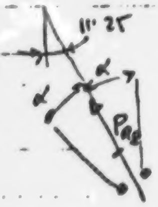
CONSEQUENTLY - RADIAL LOAD @ JOINT #8 OR 25 IS
$\frac{1}{2} \times .195C = .195 \times 340.724 = 33.22^{\#}$.

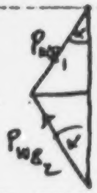


$\frac{P_{J_8}}{P_{R_8}} = \sin 11.25°$; $P_{R_8} = 170.4358^{\#}$

WITH $\alpha = 11.768$

THE CABLE TENSION DUE TO WIND @ THIS JOINT

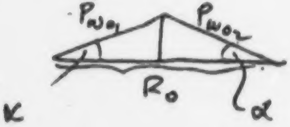




$$\frac{\frac{P_{R_8}}{2}}{P_{W8_2}} = \cos\alpha \text{ ; } P_{W8} = \frac{P_{R8}}{2 \times \cos\alpha} = \frac{170.4338}{2 \times .9789}$$

$$\underline{P_{W8_1} ; P_{W8_2} = 87.046^{\#}}$$

AT THE OTHER END, @ WP #0
$C = 340.724^{\#} = R_0$



$$\frac{R_0}{2 \times P_{W0}} = \cos\alpha \text{ ; } P_{W0_1}, P_{W0_2} = \frac{R_0}{2\cos\alpha} = \frac{340.724}{2 \times 0.9789}$$

$$P_{W0_1}, P_{W0_2} = \underline{174.034^{\#}}$$

THUS IN THE ENTIRE SEGMENT, RAD. WIND LOADS CAUSED TENSION VARIES BETWEEN $P_{W8_1} - P_{W8_2} = 87.046^{\#}$ MIN

$P_{W0_1} - P_{W0_2} = 174.034^{\#}$ MAX

NOTE: $\frac{P_{W0_1}}{P_{W8_1}} = \frac{174.034}{87.046} = 2$ BY THE CONVENTION SELECTED, WHEREBY WORST WIND DIRECTION, TOWARDS JOINT IN THE CENTER (WP_0) IS USED.

PRELOAD = $70^{\#}$/CABLE — PRELOAD SPRING SELECTION ST. STL. CABLE

SPRING SELECTED: LEE COMPRESSION SPRING #LC-125M-1
STAINLESS STL.

FREE LENGTH = 1.75",
SPRING RATE $= \frac{5}{6} \times 90 = 75^{\#}/\text{in}$ STK $= \frac{70}{75} = \underline{.933 \text{ IN}}$

CH-45 U1-70

PARA 3.1.3.1 CONT'D

COMPRESSED LENGTH OF SPRING $L_{COMPR} = 1.75 - .933 = .816$ in

SPRING DATA:

OUTSIDE DIA = 1.095"
TO WORK IN HOLE DIA = 1.125"
WIRE DIA = .125"
SPRING RATE = $90 \times \frac{5}{6} = 75$ #/in @ St. Stl.
FREE LENGTH = $1\frac{3}{4}$"
SOLID HEIGHT = .768"

ST. STEEL CABLE SELECTION: $\frac{1}{8}$" DIA, CONSTRUCTION 7×19
BREAKING STRENGTH = 2000 Lbs
$F.S = \frac{2000}{244.034} = 8.19$ OK

TOTAL LOAD ON CABLE = 174.034# (MAX WIND + ICE)
PRELOAD (SPRING) = 70.00 #
$P_{CABLE\ MAX}$ = 244.034#

PARA 3.1.3.2

EFFECTS OF DISTORTION UNDER TENSION IN ST. STL. CABLE.

RE: STRENGTH OF METAL AIRCRAFT ELEMENTS
DEPARTMENT OF AIR FORCE } US. MAR. 1955
" OF NAVY
BULLETIN No. ANC-5
FIG #. 2.6.242 LOAD-DEFORMATION DATA FOR STL. CABLE

$\frac{1}{8}$ DIA ST. STL. CABLE, 7×9 CONSTRUCTION, $E = 15.05 \times 10^6$ psi (MOD. OF ELASTICITY)

@ LOAD = 174# ELONGATION = .003 in/in
@ LOAD = 70# ELONGATION = .001 in/in
@ LOAD = 179+70 = 244# " = .0035 in/in

EFFECTIVE CABLE LENGTH = 98.86 - 6 = 92.86 in

@ 174# LOAD, ELONGATION $\Delta_1 = l_{eff} \times .003 = 92.86 \times .003 = .278$"
@ 70# LOAD, " $\Delta_2 = l_{eff} \times .001 = 92.86 \times .001 = .0928$"
@ 244# LOAD " $\Delta_3 = l_{eff} \times .0035 = 92.86 \times .0035 = .32501$#

PARA 3.1.3.2 CONT'D

BUT DURING SPRING TENSIONING, THE ELONGATION CAUSED BY THE PRETENSION OF 70# IS AUTOMATICALLY COMPENSATED FOR. THUS THE BALANCE $\Delta_3 = .3250"$

$$- \Delta_2 = \underline{.0928"}$$

$$\Delta_{eff} = .2322" \text{ Remains}$$

Δeff is the maximum elongation in the cable direction.

CONSIDERING ONLY THE RADIAL DIRECTION, ITS COMPONENT

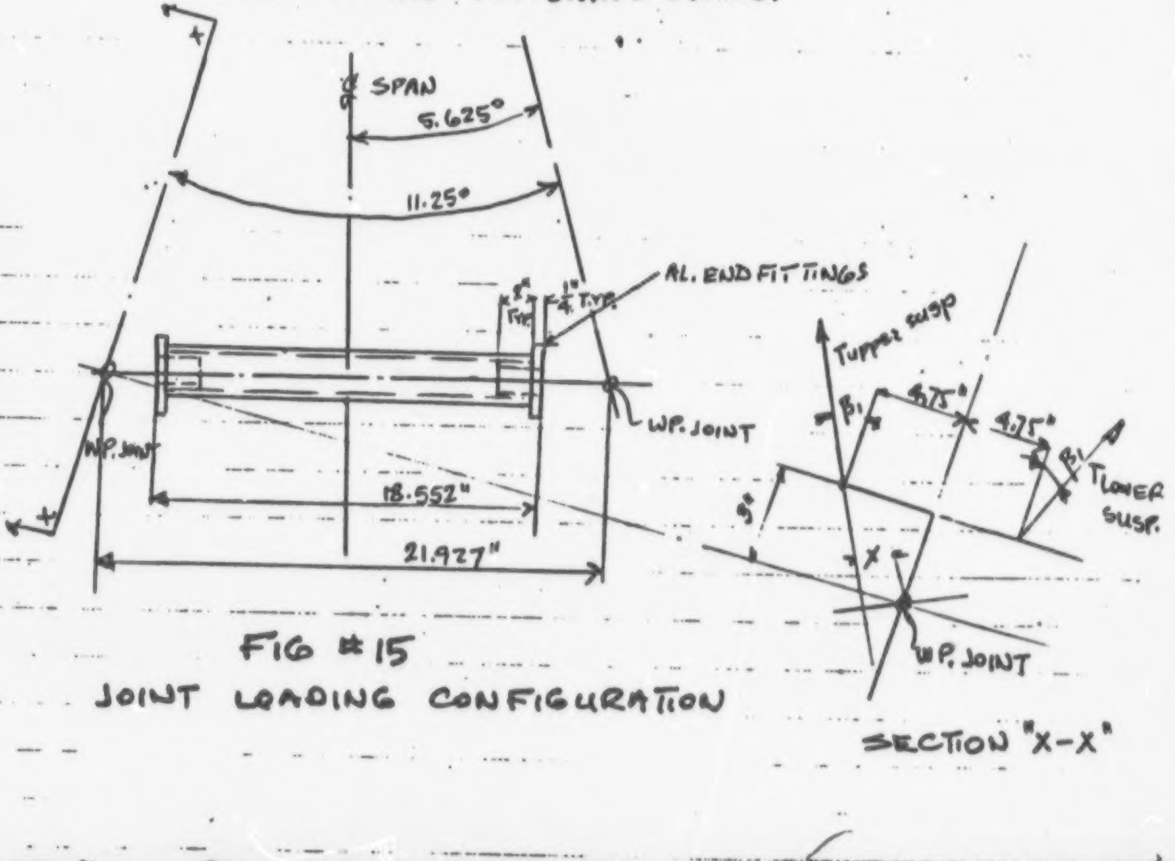
$$\Delta_{RAD} = \cos\alpha \times \Delta_{eff} = \cos 11.768 \times .2322 = \underline{\underline{.227"}}$$

THUS THE ANNULAR RING RADIAL MOVEMENT UNDER COMBINED ICE AND WIND LOAD MAY REACH $\Delta_{RAD} = .227"$ OFFSET OR

$\frac{.227}{2 \times 115.354} \times 100 = .098\%$ OF THE SPAN. (QUITE SMALL)

PARA 3.1.4 LOADING CONDITIONS AND STRESS ANALYSIS ANNULAR RING – NONMETALIC SQ. TUBING

@ THE WORST CONDITION, 2" RAD. ICE + WIND, THESE ELEMENTS ARE EXPOSED TO THE FOLLOWING LOADS.



+
℄ SPAN
5.625°
11.25°
AL. END FITTINGS
5/8" TYP
1/4" TYP
WP. JOINT
WP. JOINT
18.552"
21.927"
+
T upper susp
β1
3.75"
4.75"
β1
T LOWER SUSP.
5/8"
X
WP. JOINT
SECTION "X-X"

FIG #15
JOINT LOADING CONFIGURATION

PARA 3.1.9 CONT'D.

ACTING MOMENT – UPPER-LOWER SUSPENSION ONLY

DIMENSION $X = ?$

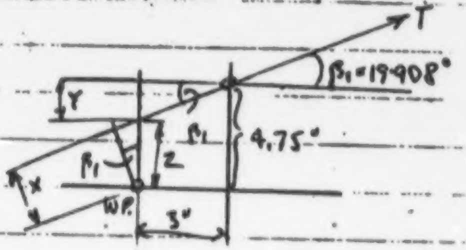

T
$\beta_1 = 19.908°$
Y
β_1
β_1
Z
4.75"
X
W.P.
3"

FIG #16

$$\frac{Y}{3} = \tan\beta_1$$

$$Y = 3 \times \tan\beta_1 = 1.086"$$

$$Z = 4.75 - Y = 3.6635"$$

$$\frac{X}{Z} = \cos\beta_1 \; ; \; X = Z \times \cos\beta_1 = \underline{3.4446"}$$

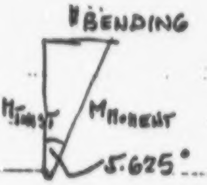
MAXIMUM LOADS – SUSPENSION @ 2" RAD. ICE + WIND

@ UPPER STRUT, TENSION $T_{U_{MAX}} = 774.52\#$

@ LOWER " , " $T_{L,MAX} = 137.17\#$

ACTING MOMENT $X \cdot (T_{U_{MAX}} - T_{L_{MAX}}) = M_{JOINT} = 3.44 \times (774.52 - 137.17) = 2192.48$ in Lbs

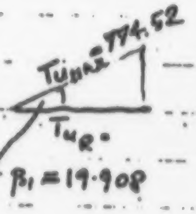
THIS MOMENT ACTS IN PLANE X-X (SEE FIG #15)
CONSIDERING SEPARATE MOMENT COMPONENTS CAUSING TWIST OR BENDING MOMENTS


M BENDING
M TWIST
M MOMENT
5.625°

$$\sin 5.625 = \frac{M_{BENDING}}{M_{JOINT}} \; ; \; M_{BENDING} = \sin 5.625 \times M_{JOINT} = \underline{214.9 \text{ in Lbs}}$$

$$M_{TWIST} = \cos 5.625 \times M_{JOINT} = \underline{2181.92 \text{ in Lbs}}$$

AXIAL LOAD ALONG 3" SQ. TUBING DUE TO UPPER/LOWER SUSP.


$T_{U_{MAX}} = 774.52$
$T_{U_R} =$
$\beta_1 = 19.908$

LOAD UPPER SUSP – RADIAL DIRECTION $= \cos\beta_1 \times T_{U_{MAX}} = \cos 19.908 \times 774.52 = 728.235\#$

– VERTICAL DIRECTION $= \sin\beta_1 \times T_{U_{MAX}} = \sin 19.908 \times 774.52 = 263.73\#$

PARA 3.1.4 CONT'D.

LOAD @ 2" RAD. ICE + WIND

LOWER SUSPENSION SYSTEM – RADIAL DIR. $= \cos\beta_1 T_{LMAX} = \cos 17.908 \times 157.17$
$= 128.97^{\#}$

" " " VERT. DIR. $= \sin\beta_1 T_{LMAX} = 46.707^{\#}$

Σ RADIAL LOAD = FROM UPPER/LOWER SUSP. $= 728.235 + 128.97 = 857.2^{\#}$
Σ VERT. LOAD $= 263.73 - 46.707 = 217.014^{\#}$

GR. PLANE RADIAL LOAD = $244.0^{\#}$
ΣRADIAL LOAD UPPER/LOWER = 857.2
$\Sigma\bar{R} = P_R = 1101.2^{\#}$ MAX

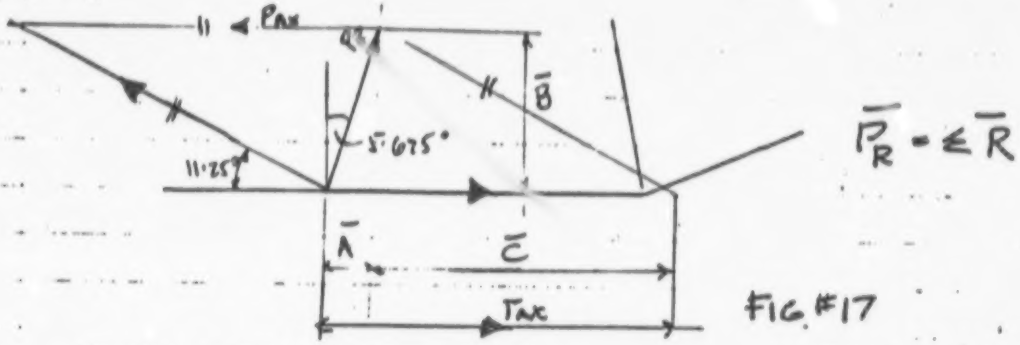


FIG. #17

WHERE FROM PARALELLOGRAM @ $90 - 5.625 = 84.375°$

$\frac{\bar{A}}{\Sigma R} = \cos 84.375$

$\bar{A} = 107.94^{\#}$

$\bar{B} = \Sigma R \sin 84.375° = 1095.99$

$\frac{\bar{B}}{\bar{C}} = \tan 11.25°$; $\bar{C} = \frac{\bar{B}}{\tan 11.25} = 5509.64^{\#}$

THUS SHEAR IN HOR. PLANE = $V_{SH\,HOR} = \bar{B} = 1095.99^{\#}$
" IN VERT. PLANE = $V_{SH\,VER} = 217.014^{\#}$
ΣAXIAL LOAD = $\bar{T}_{AX} = \bar{A} + \bar{C} = 107.94 + 5509.64 = 5617.58^{\#}$

PARA 3.1.4 CONT'D

SECTION PROPERTIES – EXTREN 3" SQ. TUBING

$d = 3"$

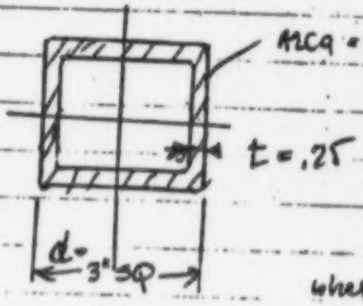
$t = .25"$

$A = 2.75 \text{ in}^2$

$I = 3.495 \text{ in}^4$

$S = 2.330 \text{ in}^3$

$r = 1.125 \text{ in}$



AXIAL LOAD – CAPACITY FIG #18

where $\frac{kl}{r} = \frac{2 \times 18.552}{1.125} = 32.98$

$$F_c = \frac{\pi^2 E}{\left(\frac{k}{r}l\right)^2} = \frac{\pi^2 \times 10^6}{(32.98)^2} = 9074 \text{ psi} ;$$

ACTUAL AXIAL STRESS

$$\sigma_{Ax} = \frac{P_{MAX}}{A} = \frac{5617.58}{2.75} = 2042.75 \text{ psi}$$

where $k = 2$ (fixity)

$l = 18.552"$

$E = 1.0 \times 10^6$ psi

$$F.S. = \frac{9074}{2042.75} = 4.44 > \underline{4.0 \text{ OK}}$$

BENDING STRESS $\curvearrowleft \curvearrowright$

$M = 214.90$ in Lbs

$$\sigma = \frac{M}{S} = \frac{214.9}{2.33} = 92.23 \text{ psi (small)}$$

TORSIONAL STRESS: $\tau = \frac{M_{TWIST}}{2t(d-t)^2} = \frac{2182.92}{2 \times .25(3-.25)^2} = 577.3 \text{ psi}$ (low)

$F.S. = \frac{5500}{577} = 9.52 >> 4.00$ OK.

WHERE $M_{TWIST} = 2182.92$ INLbs IS TWISTING MOMENT (SEE pp. #50)

BEARING STRESS $= \sigma_B = \frac{P_{MAX}}{A} = \frac{5617.58^{\#}}{2.75} = 2042.75^{\#}$ psi

$$F.S. = \frac{30000 \text{ psi}}{2042.75 \text{ psi}} = 14.68 >> 4.00$$

(NOTE: DUE TO HIGH F.S. ADHESIVE JOINT @ FLANGES MAY NOT BE MANDATORY)

PARA 4.0 C' MAST STRUCTURAL ANALISIS.

PARA 4.1 UPPER MAST LOADING CONDITIONS AND STRESS ANALYSIS.

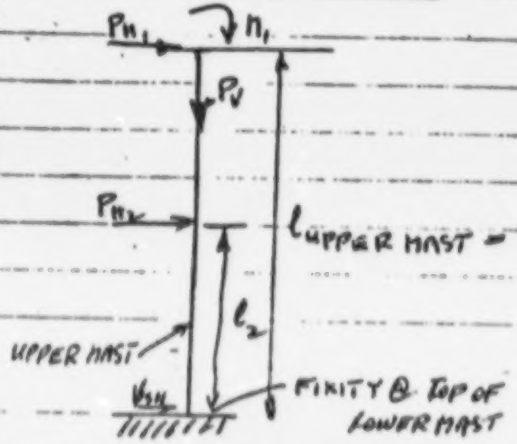


FIG. #19

WORST LOADING CONDITION @ 2" RAD. ICE + WIND, LOADS ARE AS FOLLOWS:

WIND LOAD — L. ARRESTOR 67.92#
UPPER SUSP. 430.23#
UPPER DISC 17.27#
P_{H_1} = 515.19#

@UPPER MAST + FLANGES

P_{H_2} = 47.87#

$M_1^{O.T.}$ = MOMENT DUE TO LIGHTNING ARR.

$$= \frac{178.675-128.5}{2}\ 67.92 = \underline{1703.94\ \text{in Lbs}}$$

$$M_2 = l_2 \times P_{H_2} = 47.87 \times 21 = \underline{1005.27\ \text{in Lbs}}$$

$$l_{UPPER\ MAST} = 128.5'' - 86.5 = 42''$$

$$l_2 = \frac{l_{UPP.M}}{2} = 21''$$

M_1 TRANSF. TO FIXITY — $M_1' = \left(\frac{178.675-128.5}{2} + 42\right) \times 67.92 =$

$$= 1703.94 + 42 \times 67.92 = 1703.94 + 2852.64 = 4556.58\ \text{in Lbs}$$

$$\Sigma M = M_1' + M_2 = 4556.58 + 1005.27 = 5561.85\ \text{in Lbs}$$

$$V_{SH} = \Sigma P_H = P_{H_1} + P_{H_2} = 515.19 + 47.87 = 563.06\#$$

$$P_V = 537.52 + 7792.87 + \underbrace{1007.68}_{2^{nd}\ 1/2\ \text{RED. WEIGHT INCL. ICE, UPPER SUSP. SYSTEM}} = 9338.07\#$$

PIPE PROPERTIES, 4.0" N. DIA, SCHEDULE #40 AL. PIPE

MAT'L: 6351-T6

SECTIONAL PROPERTIES:

OD = 4.50"
ID = 4.026"
WALL = .258" = t
I = 7.238 in⁴
S = 3.219 in³
r = 1.510 in
A = 3.170 in²

PARA 4.1 CONT'D.

$\frac{Kl}{r} = \frac{2 \times 42}{1.510} = 55.62$, CORRESPONDING BUCKLING STRESS

$f_c = 32520$ psi

$f_{c_{ACT.}} = \frac{P_V}{A} = \frac{9338.07}{3.17} = 2945.76$ psi $< f_c = 32520$ psi

CONSIDERING COMBINED AXIAL LOAD WITH BENDING MOMENT, WHERE

$\frac{L}{r_{min}} = \frac{42}{1.51} = 27.81$

If compressive stress, caused by axial load is $f_a = f_c = 2945.76$ psi

Bending stress caused by end moments $\quad f_b = \frac{M}{S} = \frac{5561.85}{3.214} = 1730.5$ psi

FOR SLENDERNESS RATIO BETWEEN 16 AND 140, THE ALLOWABLE STRESS

$$f_{allowable} = 15400 - (470)\sqrt{\frac{R}{t}} = 15400 - 470\sqrt{27.81} = 12921.44^{\#}$$

where $R = \frac{(4.75 - .258)}{2} = 2.246$

$$\left.\begin{matrix} R = \frac{(4.75-.258)}{2} = 2.246 \\ t = .258 \end{matrix}\right\} \frac{R}{t} = \frac{2.246}{.258} = \underline{\underline{8.706}}$$

Actual bending stress $f_b = 1730.5$ psi

" compressive stress $f_a = f_{c_{ACT}} = 2945.76$ psi

For members subjected to combined end loading and Bending

$$\frac{f_a}{F_a} + \frac{f_b}{F_b\left(1 + \frac{f_a}{F_e}\right)} \leq 1.00$$

Para 4.1 Cont'd.

where
f_a = actual compressive stress
f_b = " bending stress
F_a = allowable compressive stress
F_b = " bending stress
F_e = " buckling stress
} Based on ASTM ST6

where $\frac{f_a}{F_a} + \frac{f_b}{F_b\left(1-\frac{f_a}{F_e}\right)} \leq 1.0$; $F_e = \frac{45000}{\left(\frac{L}{r}\right)^2} = \frac{45000}{(27.81)^2} = 58.1849$ ksi

$F_a = 7.5$ ksi ; $f_a = 2.945$ ksi
$F_b = 9.5$ ksi ; $f_b = 1.73$ ksi

$$\frac{2.945}{7.5} + \frac{1.73}{9.5\left(1-\frac{2.945}{58.18}\right)} = 0.3926 + .1918 = \underline{0.58 < 1.00} \text{ OK}$$

Para 4.2 LOWER MAST-ASS'Y LOADING CONDITIONS AND STRESS ANALYSIS.

LOADING CODDITION AND GEOMETRY : (@ 2" RAD ICE + DW + WIND)

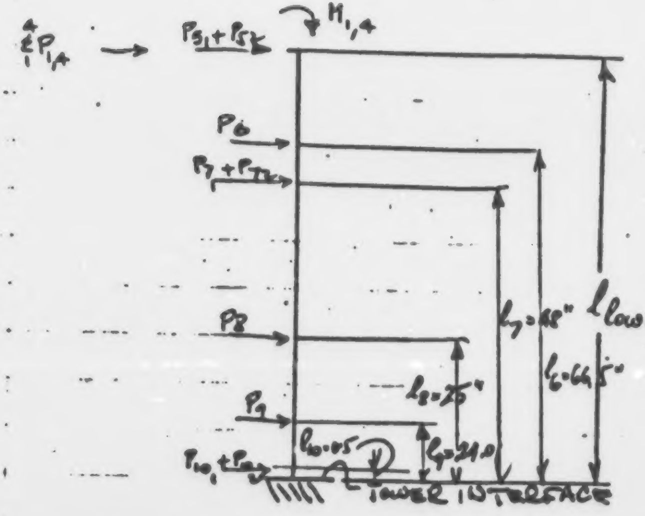

$\sum_1^4 P_{1,4}$
$P_{5_1} + P_{5_2}$
$M_{1,4}$
P_6
$P_7 + P_{7_2}$
P_8
P_9
$P_{10_1} + P_{10_2}$
$l_7 = 88"$
$l_{lower\ mast} - 86.5"$
$l_6 = 64.5"$
$l_8 = 25"$
$l_9 = 21.0$
$l_{10} = .05$
TOWER INTERFACE

FIG #20

WORST CASE, CONCENTRATED LOAD @ TOP OF MAST

$\sum_1^4 P'_{1,4} = 67.92 + 430.23 + 17.27 + 47.81 + 47.24 =$
$= 810.47$# (See pp. #27, REF)

$P'_{5_1} + P'_{5_2} = 3458.79\# + 1030.22\# = 4489.0\#$
$P'_8 = 330.8\#$
$P'_9 = 10.0\#$ | $P'_{10} = 6.73\#$

MOMENT @ BASE = 40.833 kft = ΣM

Σ SHEAR @ BASE =
$V_{SH} = \sum_1^{10} P'_{1,10} = \underline{5721.09\#}$

SH # 56 OF 70

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PARA 4.2 CONT'D.

LOWER MAST – SECTION PROPERTIES

8" N. DIA, SCHEDULE #40 STD. ALUMINUM PIPE,

MATERIAL : 6351-T6

OUTS. DIA = 8.625"
INS. DIA = 7.981"
WALL TH = .322"
I = 72.49 in⁴
S = 16.81 in³
r = 2.94 in
A (area) = 8.399 in²
WEIGHT = 9.878#/ft

$$\frac{kl}{r} = \frac{2 \times 86.5}{2.94} = 58.84$$

FOR LOCAL BUCKLING

$$\frac{R}{t} = \frac{8.625 - .322}{2 \times .322} = 12.89 \quad \text{EQUIV.} \ \frac{kl}{r} \simeq 18$$

$$f_c = 28000 - 155 \times \frac{kl}{r} = 28000 - 155 \times 18 = 25210 \text{ psi}$$

Allowable load $P = \frac{f_c}{F.S.} A = \frac{25210}{1.95} \times 8.399 = 108583.99 \text{ Lbs}$

Allowable stress, overall

$$f_{all} = 15400 - 470\sqrt{12.89} = 13712.57 \text{ psi}$$

Allowable load, overall

$$P_{all} = f_{all} A = 13712.57 \times 8.399 = 115171.92\#$$

Allowable Bending stress = 15 ksi (outer fibre)

Actual Bending Stress (compressive stress in extreme fibre)

$$\sigma = \frac{M}{S} = \frac{40833 \times 12}{16.81} = 29149.07 \text{ psi} > 15 \text{ksi}$$ Not acceptable

SOLUTION: ALT. #A IN THE LOWER PORTION OF THE LOWER MAST SUBSTITUTE SCH. #40 (PRESENT) CROSS SECTION WITH A HEAVIER CROSS SECTION PIPE, WITH SAME OD.

PARA 4.2 CONT'D.

MINIMUM SECTION MODULUS REQUIRED WITH $f = 15\,ksi$ ALLOWABLE ON EXTREME FIBER

$$\sigma_{MIN} = 15\,ksi = \frac{M}{S} = \frac{40833 \times 12}{S};$$

$$S_{MIN} = \frac{40833 \times 12}{15000} = 32.66\ in^3$$

SOLUTION "A"

BUT SCH # 120, STD. PIPE, AL. 8" N. DIA HAS $S = 32.6\ in^3$

SECTION PROPERTIES OF THIS PIPE ARE : (MAT'L : AL. 6351-T6)

NOM. DIA = 8.00 in
SCHEDULE No = 120
OD = 8.625 in
ID = 7.189 in
WALL TH = .718 in
$I = 140.6\ in^4$
$S = 32.6\ in^3$
$T = 2.81$ in
Area $A = 17.84\ in^2$
weight/FT = 20.97 #/lin ft

Length of this extra heavy pipe would be

$$M_B - M_R = M_1 = \sigma_{MIN} \times S_{SCH40} = 15000 \times 16.81$$

$$M_1 = 252150\ in\,Lbs = 21012.5\ ft\,Lbs$$

$$M_R = 40833 - 21012.5 = 19820.5\ ft\,Lbs$$

but $M_R = \Sigma W_{SH} \times \frac{a}{12} = 5721.09 \times \frac{a}{12}$

So $a = \frac{19820.5}{5721.09} \times 12 = \underline{\underline{41.57\ in}}$

Length of extra heavy pipe : 42 to 44 in

Extra dry weight due to increase in pipe wall thickness

$$\Delta weight = \frac{44}{12} \times (20.97 - 9.878) =$$

$= \underline{40.67\,\#}$ (add to own weight)

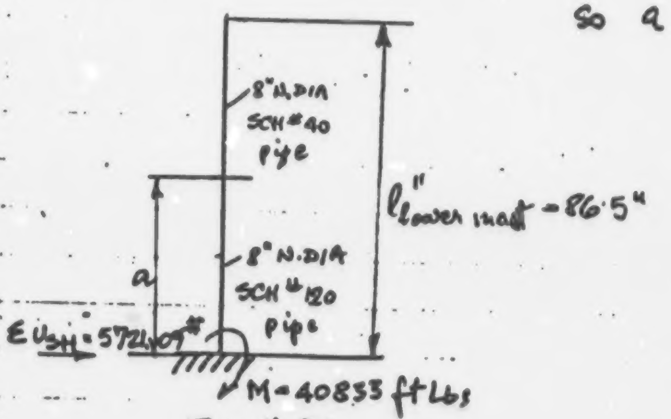


FIG # 21

PARA 4.2 CONT'D.

SOLUTION "B" IN CASE IT IS HARD TO OBSTAIN SCHEDULE #120 PIPE, SUBSTITUTE INSTEAD OF A LARGER SIZE PIPE, SAME LENGTH (42 TO 44" LG) WITH THE FOLLOWING PROPERTIES:

SOL # B/1

NOM. PIPE DIA = 10"

OD = 10.75"

SCHEDULE = 60

ID = 9.75 in

WALL TH. = 0.50 in

$I = 211.9\ in^4$

$S = 39.43\ in^3$

$t = 3.628$ in

Area = $A = 16.10\ in^2$

Weight = 18.93 #/ft

OR

SOL. # B/2

NOM. PIPE DIA = 12"

OD = 12.75"

SCHEDULE = 40

ID = 11.938"

WALL TH = .406"

$I = 302.2\ in^4$

$S = 47.4\ in^3$

$t = 4.38$ in

Area $A = 15.76\ in^2$

Weight = $18.52\ \#/ft^3$

INCREASE IN WIND LOAD, ICE LOAD AND DEADWEIGHT IF EITHER OF THESE SUBSTITUTES ARE USED IS NEGLIGABLE (SMALL)

PARA 4.3 DEFLECTION ANALYSIS – C'MAST ASS'Y.

UPPER SECTION – UNDER LOAD CONDITIONS SPECIFIED

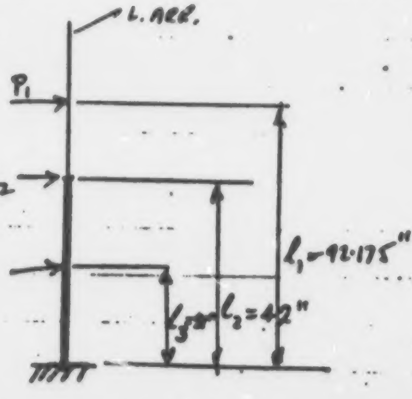
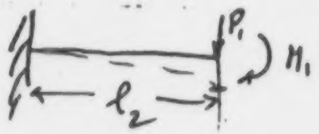


FIG #22

PARA 4.3 DEFL. ANALYSIS - CONT'D.

LOAD CONDITIONS	P_1	$P_{2_1} + P_{2,2}$	P_3
WIND LOAD - NO ICE	21.04#	77.652#	52.44#
WIND LOAD + 2" RAD ICE	67.92#	447.5#	47.87#
WIND LOAD + 1" RAD. ICE	38.94#	235.69#	37.11#

DEFLECTION DUE TO P_1



WHERE $M_1 = (\ell_1 - \ell_2) P_1 = (92.175 - 42) P_1 = 50.175 P_1$

DUE TO MOMENT $y_1 = -\frac{1}{2} \frac{M_1 \ell_2^2}{IE}$ (in)

$$\theta_1 = -\frac{M_1 \ell_2}{EI}$$

DEFLECTION DUE TO $P_{2_1} + P_{2_3}$

$$y_2 = -\frac{1}{3} \frac{P_{2,3} \ell_2^3}{EI}$$

$$\theta_2 = -\frac{1}{2} \frac{P_{2,3} \ell_2^2}{EI}$$

DEFLECTION DUE TO P_3

$$y_3 = -\frac{1}{3} \frac{P_3 \ell_3^3}{EI}$$

$$\theta_3 = -\frac{1}{2} \frac{P_3 \ell_3^2}{EI}$$

CONSIDERING WORST CASE, 2" RAD ICE + WIND, WITH $I = 7.238 \text{ in}^4$

$$y_1 = -\frac{1}{2} \frac{M_1 \ell_2^2}{IE} = -\frac{1}{2} \frac{50.175 \times 67.92 \times 42^2}{7.238 \times 10^7} = -0.041''$$ $E = 10 \times 10^6$ psi

$$\theta_1 = -\frac{M_1 \ell_2}{EI} = -\frac{50.175 \times 67.92}{7.238 \times 10^7} = -4.7 \times 10^{-5} \text{ RAD} = 9.71 \text{ ARC SEC}$$

$$y_2 = -\frac{1}{3} \frac{P_{2,3} \ell_2^3}{EI} = -\frac{1}{3} \times \frac{447.5 \times 42^3}{7.238 \times 10^7} = -.1526 \text{ in}$$

$$\theta_2 = -\frac{1}{2} \frac{P_{2,3} \ell^2}{EI} = -\frac{1}{2} \frac{447.5 \times 42^2}{7.238 \times 10^7} = -5.45 \times 10^{-3} \text{ RAD} = \underline{\underline{.312^\circ}}$$

PARA 4.3 CONT'D

$$y_3 = -\frac{1}{3}\frac{P_3 l_3^3}{EI} = -\frac{1}{3} \times \frac{47.84 \times 21^3}{7.238 \times 10^7} = -2.040 \times 10^{-3}\text{ IN}$$

$$\theta_3 = -\frac{1}{2}\frac{P_3 l_3^2}{EI} = -\frac{1}{2} \times \frac{47.84 \times 21^2}{7.238 \times 10^7} = -1.457 \times 10^{-4}\text{ RAD}$$

$= -30.06$ arc sec

TOTAL DEFL @ TIP OF BEAM

PROJECTED DEFL. DUE TO P_3 WITH $\theta_3 = 30.06$ arc sec @ 21"

$$y_3' = \tan\theta_3 \times 21 = -3.06 \times 10^{-3}\text{ IN}$$

So $\Sigma y = y_1 + y_2 + y_3 + y_3' = -.041" + (-.1526") + (-2.040 \times 10^{-3}\text{IN}) + (-3.06 \times 10^{-3}\text{IN}) =$

$\Sigma y = -\underline{\underline{.1987}}"$ @ TIP OF MAST RELATIVE TO LOWER MAST EMBEDMENT

$\Sigma\theta = \theta_1 + \theta_2 + \theta_3 = -4.7 \times 10^{-5} + (-5.4 \times 10^{-3}) + (-1.457 \times 10^{-4}) = -5.592 \times 10^{-3}$ RAD

$= \underline{.320 \text{ ARC DEGR.}}$

IN CASE OF WIND - NO ICE

$y_1 = -.012$ IN

$\theta_1 = -1.45 \times 10^{-5}$ RAD

$y_2 = -.0264$ in

$\theta_2 = -9.45 \times 10^{-4}$ RAD

$y_3 = -3.53 \times 10^{-4}$ IN ; $y_3' = -\tan\theta_3 \times 21 = -5.292 \times 10^{-4}$ IN

$\theta_3 = -2.52 \times 10^{-5}$ RAD

So $\Sigma y = -.012 + (-.0264) + (-.000353) + (-.0005292) = -.03928"$

$\Sigma\theta = (-1.45 \times 10^{-5}) + (9.45 \times 10^{-4}) + (-2.52 \times 10^{-5}) = -98.47 \times 10^{-5}$ RAD $= 0.056$ ARC DEGR

IN CASE OF WIND + 1" RAD ICE

$y_1 = -.023$ IN

$\theta_1 = -2.69 \times 10^{-5}$ RAD

$y_2 = -.0875$ IN

$\theta_2 = -3.124 \times 10^{-3}$ RAD

$y_3 = -1.1695 \times 10^{-3}$ IN $\quad y_3' = -\tan\theta_3 \times 21 = -1.75 \times 10^{-3}$ IN

$\theta_3 = -.835 \times 10^{-4}$ RAD

and $\Sigma y = (-.023) + (-.085) + (-1.1695 \times 10^{-3}) + (-1.75 \times 10^{-3}) = -.1109$ in

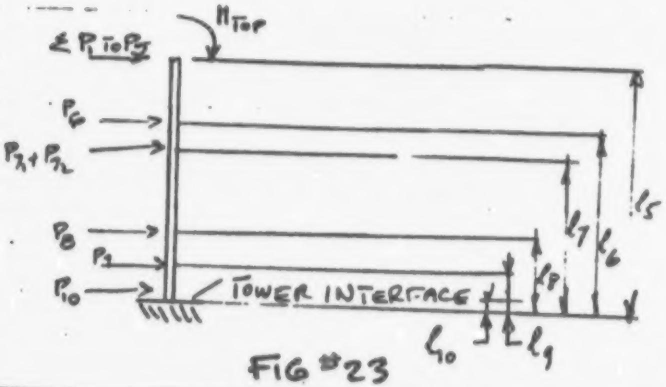
$\Sigma\theta = (-2.69 \times 10^{-5}) + (-3.124 \times 10^{-3}) + (-.835 \times 10^{-4}) = -3.234 \times 10^{-3}$ RAD $= -.185$ ARC DEG.

PARA 4.3 CONT'D.

SUMMARY OF LATERAL + ANGULAR DEFORMATIONS @ TIP OF UPPER MAST CONSIDERING FIXITY @ INTERFACE WITH LOWER MAST.

LOADING CONDITION	Σ LAT. DEFL.	Σ ANGULAR DEFL.
@ WIND – NO ICE	−.0392 in	− .056 ARC DEG.
@ WIND + 2" RAD ICE	−.1987 in	− .320 ″ ″
@ WIND + 1" RAD ICE	−.1109 in	− .185 ″ ″

PARA 4.3.1 LOADS + DEFL. ANALYSIS – LOWER MAST SECTION


M_{TOP}
ΣP_1 TO P_5
P_6
$P_7 + P_{71}$
P_8
P_9
P_{10}
TOWER INTERFACE
l_5
l_6
l_7
l_8
l_9
l_{10}

WHERE $l_5 = 86.5"$
$l_6 = 66.5"$
$l_7 = 48"$
$l_8 = 25"$
$l_9 = 5"$
$l_{10} = 0.5"$

FIG #23

LOADING COND. LOWER MAST	MOMENT M_{TOP} IN LBS	ΣP_{TOP_5} LBS	P_6 LBS	P_7 LBS	P_8 LBS	P_9 LBS	P_{10} LBS
WIND – NO ICE	12813.35	2041.16	89.106	70.00	401.77	24.01	3.575
WIND + 2" RAD ICE	20655.33	5123.59	48.8	51.42	330.797	10.00	6.73
WIND + 1" RAD ICE	15039.18	2910.39	57.188	129.81	257.92	10.00	2.98

PARA 4.3.1 CONT'D

DEFLECTION DUE TO MOMENT @ TOP $y_1 = -\frac{1}{2}\frac{M l_s^2}{EI}$

ANGULAR DEFL. DUE TO MOMENT @ TOP $\Theta_1 = -\frac{M l_s}{EI}$

DEFL. DUE TO CONCENTR. LOAD $y = -\frac{1}{3}\frac{P l^3}{EI}$

ANGULAR DEFL. DUE TO CONC. LOAD $\theta = -\frac{1}{2}\frac{P l^2}{EI}$

HOWEVER, DUE TO A "STEP" IN THE LOWER MAST CROSS SECTION @ 44" ELEVATION (OVERALL HEIGHT = 86.5") ALL DEFLECTIONS SHALL BE DERIVED IN MULTIPLE STEPS.

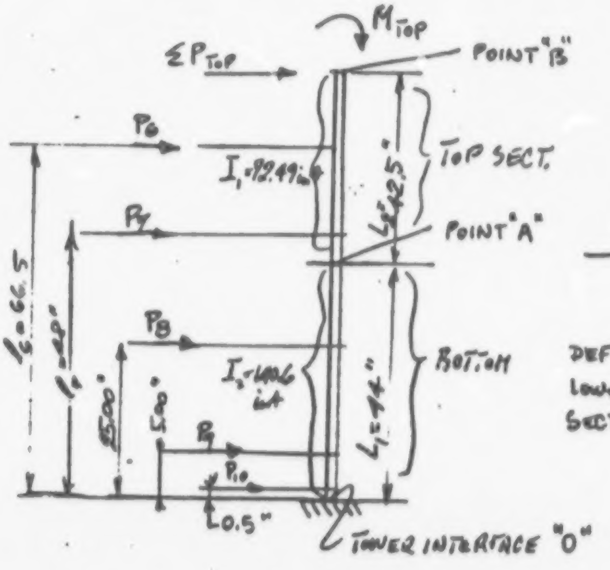


FIG # 24

ALL DEFLECTIONS DERIVED FROM LOADS, LOCATED ABOVE POINT "A" WILL BE CONSIDERED FIRST

LATERAL DEFL. @ POINT "A" DUE TO MOMENT M_{TOP}

IN THE CASE OF WIND – NO ICE:

DEFL. LOWER SECTION

$$\begin{cases} y^1_{M_A} = -\frac{1}{2}\frac{M l_{44}^2}{EI_1} = -\frac{1}{2}\frac{12813.35\times 44^2}{140.6\times 10^7} = -8.82\times 10\ \text{in} \\ \Theta^1_{M_A} = -\frac{M l_{44}}{EI_1} = -\frac{12813.35\times 44}{140.6\times 10^7} = 4\times 10^{-4}\ \text{RAD.} \end{cases}$$

DEFL. LOWER SECT.

$$\begin{cases} y^2_{M_A} = -\frac{1}{2}\frac{M l_{42.5}^2}{EI_2} = -\frac{1}{2}\cdot\frac{12813.35\times 42.5^2}{72.49\times 10^7} = -.0159" \\ \Theta^2_{M_A} = -\frac{M l_{42.5}}{EI_2} = -\frac{12813.35\times 42.5}{72.49\times 10^7} = 7.51\times 10^{-4}\ \text{RAD} \end{cases}$$

DUE TO ΣP_{TOP}, DEFL. @ BOTTOM, BETW. POINTS "O" AND "A"

LATERAL DEFL. @ POINT A

BOTTOM

$$\begin{cases} y_A = -\frac{1}{6}\frac{\Sigma P_{TOP}}{EI_2}\left(L_2^3 - 3L_1^2 L_2 + 2L_1^3\right) = -\frac{1}{6}\frac{2041.16}{140.6\times 10^7}\left(\underbrace{42.5^3 - 3\times 42.5\times 44 + 2\times 44^3}_{241523.6249}\right) \\ y_A = -.0584\ \text{in} \\ \theta_A = -\frac{1}{2}\frac{\Sigma P_{TOP} L_1^2}{EI} = -\frac{1}{2}\times\frac{2041.16\times 44^2}{} = -1.4052\times 10^{-3}\ \text{RAD} \end{cases}$$

PARA 4.3.1 CONT'D

TOP SECTION:

$$\text{TOP SECTION}\left\{\begin{aligned} y_5 &= -\frac{1}{3}\,\frac{\Sigma P_{TOP} L_2^3}{E I_1} = -\frac{1}{3}\times\frac{2041.61\times 42.5^3}{72.49\times 10^7} = -.0720'' \\ \theta_5 &= -\frac{1}{2}\,\frac{P_{TOP} L_2^2}{E I_1} = -\frac{1}{2}\cdot\frac{2041.61\times 42.5^2}{72.49\times 10^7} = 2.54\times 10^{-3}\ \text{RAD.} \end{aligned}\right.$$

DUE TO $P_6 = 89.106\#$ @ $l_6 = 66.5''$

$$\text{Bottom}\left\{\begin{aligned} y_{6A} &= -\frac{1}{6}\,\frac{P_6}{E I_2}\times\Big[\underbrace{(l_6-L_1)^3 - 3\times(l_6-l_1)\times l_1 + 2\times L_1^3}_{93604.62}\Big] = -9.887\times 10^{-4}\ \text{IN} \\ \theta_{6A} &= -\frac{1}{2}\,\frac{P_6 L_1^2}{E I_2} = -6.134\times 10^{-5}\ \text{RAD.} \end{aligned}\right.$$

$$\text{Top}\left\{\begin{aligned} y_{6B} &= -\frac{1}{3}\,\frac{P_6(l_6-l_1)^3}{E I_1} = -\frac{1}{3}\times\frac{89.106\times(66.5-44)^3}{72.49\times 10^7} = -4.66\times 10^{-4}\ \text{in} \\ \theta_{6B} &= -\frac{1}{2}\,\frac{P_6(l_6-L_1)^2}{E I_1} = -\frac{1}{2}\cdot\frac{89.106(66.5-44)^2}{77.49\times 10^7} = -3.11\times 10^{-5}\ \text{RAD} \end{aligned}\right.$$

DUE TO $P_7 = 70\#$ @ $l_7 = 48''$

$$\text{BOTTOM SECT.}\left\{\begin{aligned} y_{7A} &= -\frac{1}{6}\,\frac{P_7}{E I_2}\times\Big[\underbrace{(l_7-L_1)^3 - 3\times(l_7-L_1) + 2\times L_1^3}_{170419.99}\Big] = -1.414\times 10^{-3}\ \text{IN} \\ \theta_{7A} &= -\frac{1}{2}\times\frac{P_7\times L_1^2}{E I_2} = -\frac{1}{2}\,\frac{70\times 44^2}{140.6\times 10^7} = -4.819\times 10^{-5}\ \text{RAD} \end{aligned}\right.$$

$$\text{TOP SECT.}\left\{\begin{aligned} y_{7B} &= -\frac{1}{3}\,\frac{P_7(l_7-L_1)^3}{I_1 E} = -\frac{1}{3}\times\frac{70\times 4^3}{72.49\times 10^7} = -2.06\times 10^{-6}\ \text{IN} \\ \theta_{7B} &= -\frac{1}{2}\,\frac{P_7(l_7-L_1)^2}{E I_1} = -\frac{1}{2}\,\frac{70(48-44)^2}{72.49\times 10^7} = -7.72\times 10^{-7}\ \text{RAD} \end{aligned}\right.$$

DUE TO $P_8 = 401.77\#$ @ $l_8 = 25''$

$$y_8 = -\frac{1}{3}\,\frac{P_8 l_8^3}{I_2 E} = -\frac{1}{3}\cdot\frac{401.77\times 25^3}{140.6\times 10^7} = -1.488\times 10^{-3}\ \text{IN}$$

$$\theta_8 = -\frac{1}{2}\,\frac{P_8 l_8^3}{E I_2} = -\frac{1}{2}\,\frac{401.77\times 25^2}{140.6\times 10^7} = 8.929\times 10^{-5}\ \text{RAD}$$

PARA 4.3.1 CONT'D

DUE TO $P_9 = 24.01^{\#}$ @ $l_9 = 5.0''$

$$y_9 = -\frac{1}{3}\frac{P_9 l_9^3}{I_2 E} = -\frac{1}{3}\frac{24.01 \times 5^3}{140.6 \times 10^7} = -7.14 \times 10^{-7}$$

$$\theta_9 = -\frac{1}{2}\frac{P_9 l_9^2}{I_2 E} = -\frac{1}{2}\frac{24.01 \times 5^2}{140.6 \times 10^7} = -2.13 \times 10^{-7}\ \text{RAD}$$

neglect these, too small

Similarly neglect compliance of $P_{10} = 3.575^{\#}$ @ $l_{10} = 0.5''$

TOTAL DEFL. AND ANGULAR DEFORMATION @ WIND–NO ICE

ROTATIONAL COMPLIANCE DUE TO LOWER MAST DISTORTION UNDER MOMENT

$\theta'_{MA} = -4 \times 10^{-4}$ RAD $= -.02291^\circ$; $\tan\theta'_{MA} \times L_2 = -.0169'' = y_{MA_1}$

UNDER ΣP_{TOP}

$\theta_A = -1.405 \times 10^{-3}$ RAD $= -.0805^\circ$; $\tan\theta_A \times L_2 = -.0618'' = y_{\Sigma P_2}$

UNDER P_6

$\theta_{6_A} = -6.139 \times 10^{-5}$ RAD $= -.00351^\circ$; $\tan\theta_{6A} \times L_2 = -.00269'' = y_{6_2}$

UNDER P_7

$\theta_{7A} = -4.819 \times 10^{-5}$ RAD $= -.00276^\circ$; $\tan\theta_{7A} \times L_2 = -.00212'' = y_{7_2}$

SUMMARY OF LATERAL DEFL. WIND – NO ICE CASE

$$\Sigma y = y'_{MA} + y^2_{MA} + y_A + y_B + y_{6A} + y_{6B} + y_{7A} + y_{7B} + y_8 + y_9 + y_{MA_1} + y_{\Sigma P_2} + y_{6_2} + y_{7_2} = -\underline{\underline{0.2429''}}$$

SUMMARY OF ANGULAR DEF. WIND – NO ICE CASE

$$\Sigma\theta = \theta'_{MA} + \theta^2_{MA} + \theta_A + \theta_B + \theta_{6A} + \theta_{6B} + \theta_{7A} + \theta_{7B} + \theta_8 = 5.326 \times 10^{-3}\ \text{RAD}$$

$= .305^\circ$ (ANG. DEG.)

PARA 4.3.1 CONT'D

IN THE CASE OF 2" RAD ICE + WIND

$y'_{MA} = -.0142$ in
$\theta'_{MA} = -6.44 \times 10^{-4}$ RAD
$y'_{1'A} = -.0256$ in
$\theta'_{1'A} = -1.7106 \times 10^{-3}$ RAD
$y_A = -.1466$ in
$\theta_A = -3.527 \times 10^{-3}$ RAD
$y_B = -.180$ in
$\theta_B = -6.375 \times 10^{-3}$ RAD
$y_{6A} = -5.415 \times 10^{-4}$ IN
$\theta_{6A} = -3.359 \times 10^{-5}$ RAD
$y_{6B} = -2.55 \times 10^{-6}$ IN
$\theta_{6B} = -1.703 \times 10^{-5}$ RAD
$y_{7A} = -.586 \times 10^{-3}$ IN
$\theta_{7A} = -1.999 \times 10^{-5}$ RAD
$y_{7B} = -.854 \times 10^{-6}$ IN
$\theta_{7B} = -3.20 \times 10^{-7}$ RAD
$y_8 = -1.225 \times 10^{-3}$ IN
$\theta_8 = -7.35 \times 10^{-5}$ RAD
$y_{MA_1} = -.02724$ IN
$y_{ER_2} = -.1551$ IN
$y_{6_2} = -1.473 \times 10^{-3}$ IN
$y_{7_2} = -1.557 \times 10^{-3}$ IN

$\Sigma y = -.\underline{5545}$" @ TOP OF LOWER MAST
$\Sigma\theta = -\underline{0.011901}$ RAD = .6818 ARC DEGR.

LATERAL AND ANGULAR COMPLIANCE - LOWER MAST SECTION UNDER WIND + 2" RAD. ICE LOADS.

IN THE CASE OF 1" RAD ICE + WIND

$y'_{MA} = -.01033$ in
$\theta'_{MA} = -4.6889 \times 10^{-4}$ RAD
$y'_{1'A} = -.0186$ IN
$\theta'_{1'A} = -8.8143 \times 10^{-4}$ RAD
$y_A = -.0872$ IN
$\theta_A = -2.00 \times 10^{-3}$ RAD
$y_B = -.102$ IN
$\theta_B = -3.621 \times 10^{-3}$ RAD
$y_{6A} = -6.345 \times 10^{-4}$ IN
$\theta_{6A} = -3.436 \times 10^{-5}$ RAD
$y_{6B} = -2.988 \times 10^{-6}$ IN
$\theta_{6B} = -1.995 \times 10^{-5}$ RAD
$y_{7A} = -5.046 \times 10^{-7}$ IN
$\theta_{7A} = -5.048 \times 10^{-5}$ RAD
$y_{7B} = -2.155 \times 10^{-6}$ IN
$\theta_{7B} = -8.07 \times 10^{-7}$ RAD
$y_8 = -.955 \times 10^{-3}$ IN
$\theta_8 = -5.73 \times 10^{-5}$ RAD
$y_{MA_1} = -.0198$ IN
$y_{ER_2} = -.088$ IN
$y_{6_2} = -1.726 \times 10^{-3}$ IN
$y_{7_2} = -3.93 \times 10^{-3}$ IN

$\Sigma y = -.3345$" @ TOP OF LOWER MAST
$\Sigma\theta = -7.139 \times 10^{-3}$ RAD = .409 ARC DEGR.

LATERAL AND ANGULAR COMPLIANCE LOWER MAST SECTION UNDER WIND + 1" RAD. ICE LOADS.

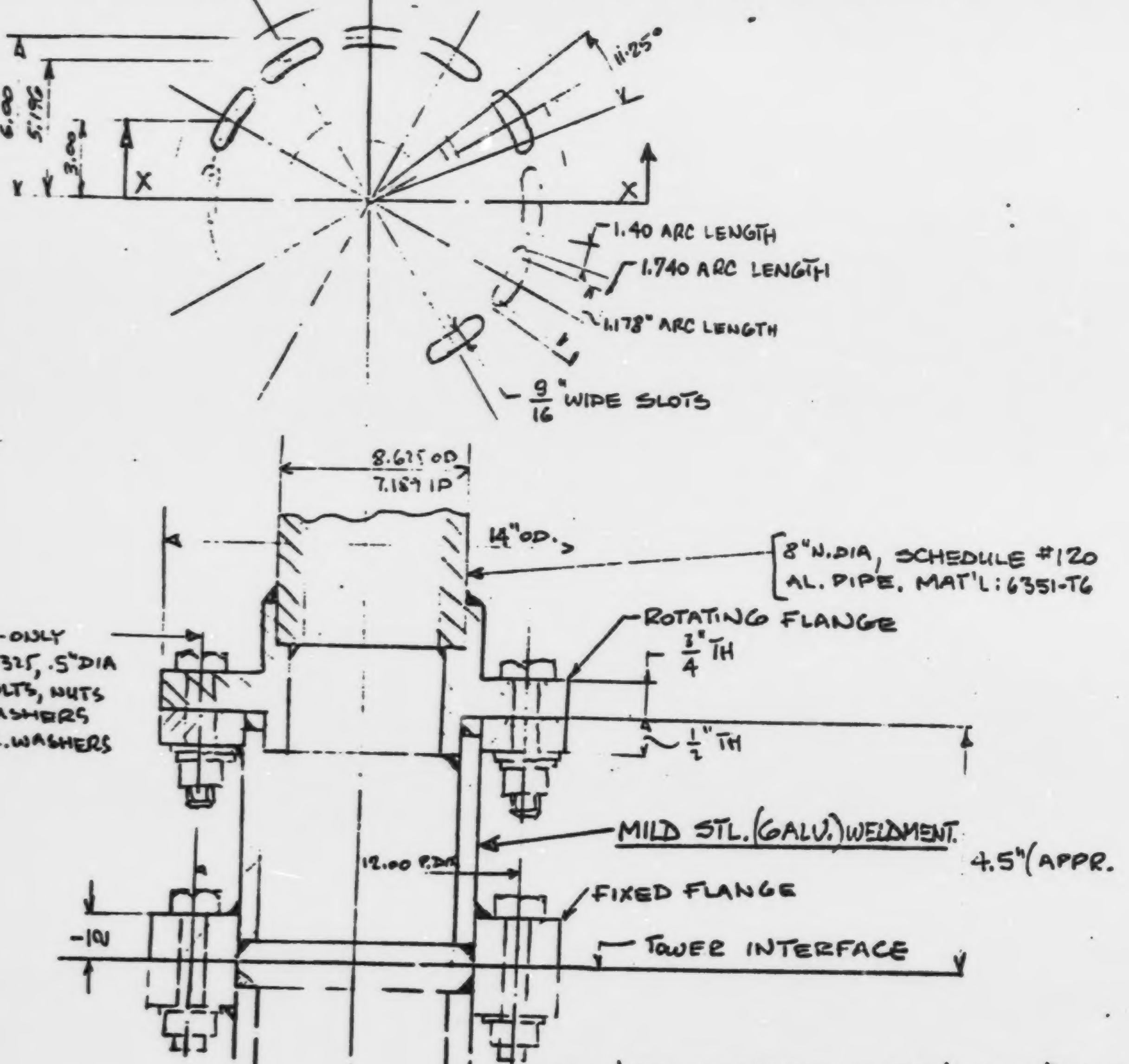
PARA 4.3.1 CONT'D

SUMMARY: DEFL. - TOP OF UPPER AND LOWER [illegible] AT VARIOUS LOADING CONDITION[illegible]

LOCATION OF DEFORMATION	UNDER MAX WIND COND. NO ICE	UNDER WIND + 2" RAD. ICE	UN[illegible] [illegible] RA[illegible]
LATERAL DEFL. LOWER MAST	-.243 IN	-.554 IN	- 3345 [illegible]
ANGULAR DEFL. LOWER MAST	.305 ARC. DEG	-.6818 ARC. DEG	- 409 [illegible]
LATERAL-DEFL. UPPER MAST (ISOLATED)	-.0392 IN	-.1987 IN	- 110[illegible]
ANGULAR DEFL. UPPER MAST ISOLATED	-.056 ARC DEG	-.320 ARC DEG	- 185 [illegible]
LATERAL DISPL. DUE TO LOWER MAST ANG. ROT	-.223 IN	-.449 IN	- 2[illegible]
TOTAL LATERAL MOVEMENT AT TOP OF UPPER MAST	-.243-.0392-.223 = = -.5052"	-.554-.1987-.449 = = -1.201"	-3345 [illegible]
TOTAL ANGULAR ROTATION AT TOP OF UPPER MAST	-.305-.056 = = .361 ARC DEG	-.6818-.32 = = 1.00 ARC DEG	-.409 - .185 [illegible] .594 [illegible]

PARA 4.4 BOTTOM FLANGE GEOMETRY, ANCHOR BOLTS LOADINGS @ TOWER INTERFACE.

THE PROPOSED GEOMETRY BELOW APPLIES ONLY IF THE LOWER MAST SIZE, "SOLUTION A" IS USED, AS SHOWN ON SH#58. IN CASE, SOLUTION B/1 OR B/2 (SEE SH#59) IS USED, THAN MODIFICATIONS WILL BE CARRIED OUT TO THIS SOLUTION.


11.25°
6.8
5.186
3.8
X
X
1.40 ARC LENGTH
1.740 ARC LENGTH
1.178" ARC LENGTH
9/16" WIDE SLOTS
8.625 OD
7.189 ID
14" OD.
8" N.DIA, SCHEDULE #120
AL. PIPE. MAT'L: 6351-T6
ROTATING FLANGE
3/4" TH
1/2" TH
12-ONLY A-325, .5" DIA BOLTS, NUTS WASHERS + L.WASHERS
MILD STL. (GALV.) WELDMENT.
4.5" (APPR.
12.00 P.DIA
FIXED FLANGE
-1IN
TOWER INTERFACE
1/2 DIA A325 BOLTS, 12-REQ'D ON 12" P.DIA
SUGGESTED IMBEDDED STEEL PIPE (OR TUBE) IN UPPER SECTION OF TOWER

SECTION X-X

BOTTOM FLANGE GEOMETRY

FIG #25

PARA 4.4 CONT'D.

SIZING OF ANCHOR BOLTS:

CSA S16 STD. ALLOWS FOR A-325 BOLTS THE FOLLOWING TENSION

$\frac{1}{2}$ SIZE – 12 KIPS/BOLT

$\frac{5}{8}$ SIZE – 19 KIPS/BOLT

$\frac{3}{4}$ SIZE – 28 KIPS/BOLT

MAX LOADS @ TOWER INTERFACE
@ WINDS + 2" RAD. ICE (RE, SEE SH#32)
OVERTURNING MOMENT $M = 40833.03$ Ft Lbs
HOR. SHEAR $V_{SH} = 5721.49\#$
VERT. LOAD, DW + ICE LOAD $P_V = 14117.58\#$

ASSUMING 12-BOLTS PER JOINT ON A 12.00 P. DIA
BALANCING THE OVERTURNING MOMENT $M = 40833.03$ Ft Lbs THE INDIVIDUAL BOLT TENSIONS (FOR BOLT ARMS, SEE FIG #25 ON SH #58)

$$M = 12.00T + 2 \times 2 \times 5.196T + 2 \times 2 \times 3T = 44.784T$$

$$T = (\text{BOLT TENSION } \#) = \frac{40833.03 \times 12}{44.784} = 10941.32\#\ \text{TENSION}/\text{BOLT}$$

THIS BOLT TENSION IS REDUCED BY THE ACTING VERTICAL LOAD ON THE JOINT

$$\frac{P_V}{12} = \frac{14117.58}{12} = 1176.47\# = P_{V_{BOLT}}$$

SO ACT. BOLT TENSION $T_{ACT} = 10941.32 - P_{V_{BOLT}} = 9764.85\#/\text{BOLT}$

SELECTING $\frac{1}{2}$ SIZE BOLTS $F.S = \frac{12000}{9764.85} = 1.225$ OK.

SHEAR LOAD/BOLT $= \frac{5721.49}{12} = 476.2\#/\text{BOLT}$

OR WITH .1419 in² STRESS AREA / ½ BOLT

$$\tau_{SH} = \frac{476.8}{.1419} = 3360.04 \text{ psi} \quad \text{LOW. OK.}$$

[redacted]

PARA 4.4 CONT'D.

FRICTION COEFF. BETWEEN BOLTED SURFACES $\mu = 0.74$
(FROM MARK'S HANDBOOK)

MINIMUM VERTICAL CLAMPING FORCE REQ'D $= \frac{5721.5}{0.74} = 7731.75$#

ASSUMING @ 12" PDIA 12 BOLTS, $\frac{1}{2}$ DIA
TOTAL CLAMPING FORCE = 12 × 12 KIPS = 144 KIPS = 144000#
CONSERVATIVELY, IF ASSUMING FULL REDUCTION IN CLAMPING LOAD DUE TO OVERTURNING MOMENT, THAN THE RESIDUAL CLAMPING FORCE

$$P_{CLAMP} = \Sigma P_{BOLT\ TENS} - \Sigma P_{BOLTS\ MOMENT} + P_V$$

$$P_{CLAMP} = 144000 - 2 \times 5 \times 10941.32 + 14117.58 = 48704.38\#$$

$$F.S = \frac{48704.38}{7731.75} = 6.29 \quad \text{OK.}$$

THIS F.S. IS HIGHER, SINCE THE O.T. MOMENT WANTS TO SEPARATE FLANGES ON ONE SIDE ONLY.

APPENDIX 5

COPIES OF MONTHLY REPORTS

DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE
RADIO DIRECTION FINDER

Interim Report

For The Period June 1981 To January 1982

DSS File No. DSS #12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

Prepared for Transport Canada, Research
and Development Centre

By: W. Jones
Project Leader

CONTENTS

1. Progress Report

2. Updated Schedule

3. Revised Cash Flow

4. Revised Specification

5. List of Long Lead Items

6. Statement Concerning Tests Conducted at Granby, January 1982

DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO
DIRECTION FINDER

Progress Report No. 1

For The Period June 1981 To January 1982

DSS File No. PSS #12ST, T8200-1-1515

Prepared for Transport Canada, Research
and Development Centre

Bayly Engineering
W.O. 290006

By: W. Jones
Project Leader

Distribution

TDC (5)
Science Procurement Manager (1)
TC, Telcom and Electronics Branch (1)

1. Scope

This is the first progress report on the development of the Quasi-Doppler RDF System for Marine purposes covering the period from June 12, 1981 to January 31, 1982.

The end of this period marks the completion of Phase I of the development as per the terms of the contract.

2. Current Status

To the end of this period, development of the Marine System has been conducted simultaneously with that of the ATC System. Therefore, it is necessary to refer to Progress Report #13, of the ATC System, which constitutes the final report of this system and the termination of Phase I of the Marine System.

3. Future Progress Reports

These will deal specifically with the Marine System Development.

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DEVELOPMENT, DESIGN, CONSTRUCTION AND TESTING OF A PROTOTYPE DOPPLER RADIO DIRECTION FINDER

(UP-B-175)

FINAL

PROGRESS REPORT NO. 13

FOR THE PERIOD 05.12.81 - 02.02.81

DSS File No. 09SD.T8300-9-0530	Bayly Engineering W.O. 260004

Prepared for Transport Canada, Research and Development Centre

by: Z.A. Krajewski
Project Leader

Distribution:

TDC - (5)
Science Procurement Manager - (1)
TC, Telecom and Electronics Branch (AIR) - (1)

BAYLY
ENGINEERING
LIMITED

1. Scope

This is the thirteenth and final progress report on the development of the Doppler DF System for ATC, covering the period of December 8, 1981 to February 2, 1982. The end of this period marks the completion of the System Prototype under the Development Contract in readiness for installation at a pre-arranged evaluation site at Kingston Airport.

2. Current Status

During the reporting period, work has been carried out at the Granby Plant of Bayly Engineering. Testing of the antenna array, and of the Receiver and Antenna Units, have been completed and pronounced satisfactory to proceed to the field test. Installation at Kingston Airport has been scheduled for the first week of February, 1982 (weather permitting).

3. Personnel

Engaged on the project full time or part-time were:

System Integration - K. Urbatzka

Receiver Design and Troubleshooting - C. Lapointe

Antenna Array - R. Labonte

Signal Processing - P. Vlitas/D. Stern

Mechanical Problems - F. Weilandt

Antenna Switching - D. Pierce

Z.A. Krajewski has returned to work on February 1, 1982 on a part-time basis, for a gradual re-entry into this program.

Ken Baxter (Mechanical Design) has been replaced by Ross Beck to take care of the complete drawing package.

Don Rees has continued throughout with the work on the system manuals.

4. Work Accomplished

Antenna Array

Following troubleshooting and correct alignment of the antenna elements and connecting cables, the antenna array was tested for phase and amplitude patterns for a range of frequencies covering the band in use. Thanks to the rotating mast at the Granby Antenna test site, and using the automatic plotting available, it was possible to obtain a comprehensive collection of antenna pattern graphs from which calculations could be made to predict the system performance. A description of this work, and the results, will be contained in a separate section of the technical report.

DF Receiver

The two channel DF receiver was troubleshooted and aligned to work with acceptable sensitivity and the correct bandwidth of 15 kHz. The receiver pair operates now with a new digital phase detector which is provided with linear response of ±180 degrees.

Audio and Emergency Channel Receivers

The modules which make up the audio and the emergency channel receivers have been fitted with the long-awaited correct filters and are now operational. However, owing to priorities given to the DF function, it is not yet certain to what extent they meet the target specification. These tests will be included in the field trials following the installation at the airport.

Frequency Synthesizer

The frequency synthesizer developed for the prototype is now performing correctly on a non-interrupted run of the equipment, but tends to be temperature sensitive over the upper portion of the band. In this condition, it can be used in the airport trials as it is after a suitable warm-up. It is planned to incorporate an improvement to eliminate the temperature affect.

Antenna Assembly

The antenna array is a mechanical assembly of very high precision. To provide this accuracy, special procedures were set-up and support jigs were designed in order to assemble it together from its parts and to erect it on a mast, for each stage of assembly. The routine was tried out in Granby by a company construction team, with excellent results.

DF System Tests

A number of system tests have been performed in Granby at the antenna test site, using the complete DF System. These included:

Receiver noise figure

DF sensitivity

DF bearing error

Response time

Audio reception

Receiver control functions (local and remote)

Performance of display facilities

All the antenna and receiver tests were made at several frequencies chosen across the 1175.-136.5 MHz band.

Field Test Procedures

Drafting of field test procedures was started with the aim of having it available at the test site when the installation is completed. Certain auxiliary system functions, such as AFC, S/N ratio, signal injection, etc., will be verified at the same stage.

5. Visits and Meetings

Mr. T. Rudback and Mr. S. Paikera of Transport Canada visited Granby on January 19, 1982 for a meeting with the Bayly team concerned with this project. A status report was submitted by K. Urbatzka, dated December 19, 1981. Other items on the agenda included:

- discussion on requirement for manuals
- quotation for work on installation
- future review meeting for the follow-up project of developing the Marine RDF system.

6. Conclusion

By completion of the Development Prototype in its readiness for installation for evaluation, the R & D Contract for this project can now be closed.

2) Updated Schedule

The previous schedule was submitted as part of Status Report (July 12, 1982) W. Jones included the PERT chart dated June 17, 1982.

This schedule was contingent on certain input from the ATC System.

The new schedule is based on full approval resulting from the Design Review meeting. Within this schedule, there is the finalisation of four tasks common to both ATC and Marine projects. These are:

1) Repackaging of the DF Receiver
2) Redesign of the Omni, Audio and Emergency channels
3) Improved System Interfacing
4) Test Injection

The remaining nine tasks are Marine Developments only.

The schedule indicates that from the CDR date, the project is to be completed in 41 weeks composing 296 man weeks, breaking down as follows:

Engineers	112 man weeks
Technologists	125 man weeks
Drafting	59 man weeks

This does not include environmental testing, manuals, test procedures, reports, etc., dealing only with matters to the completion of field trials at Granby P.Q.

The project team involved in the development of the Marine project is constituted as follows:

Engineering Supervisor	Z.A. Krajewski
Receiver Design & System Integration	C. Lapointe
Antenna (electrical)	R. Labonte
Antenna (mechanical)	F. Weilandt
Signal Processing	D. Vakili F. Baehr
RF Filters, Omni, Audio & Emergency	D. Pierce

Synthesizer	D. Authier
Bearing Processor	M. Lebeau
Documentation	R. Beck
Project Leader	W. Jones
Contracts Administration	E. Mann

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LIMITED

AEG

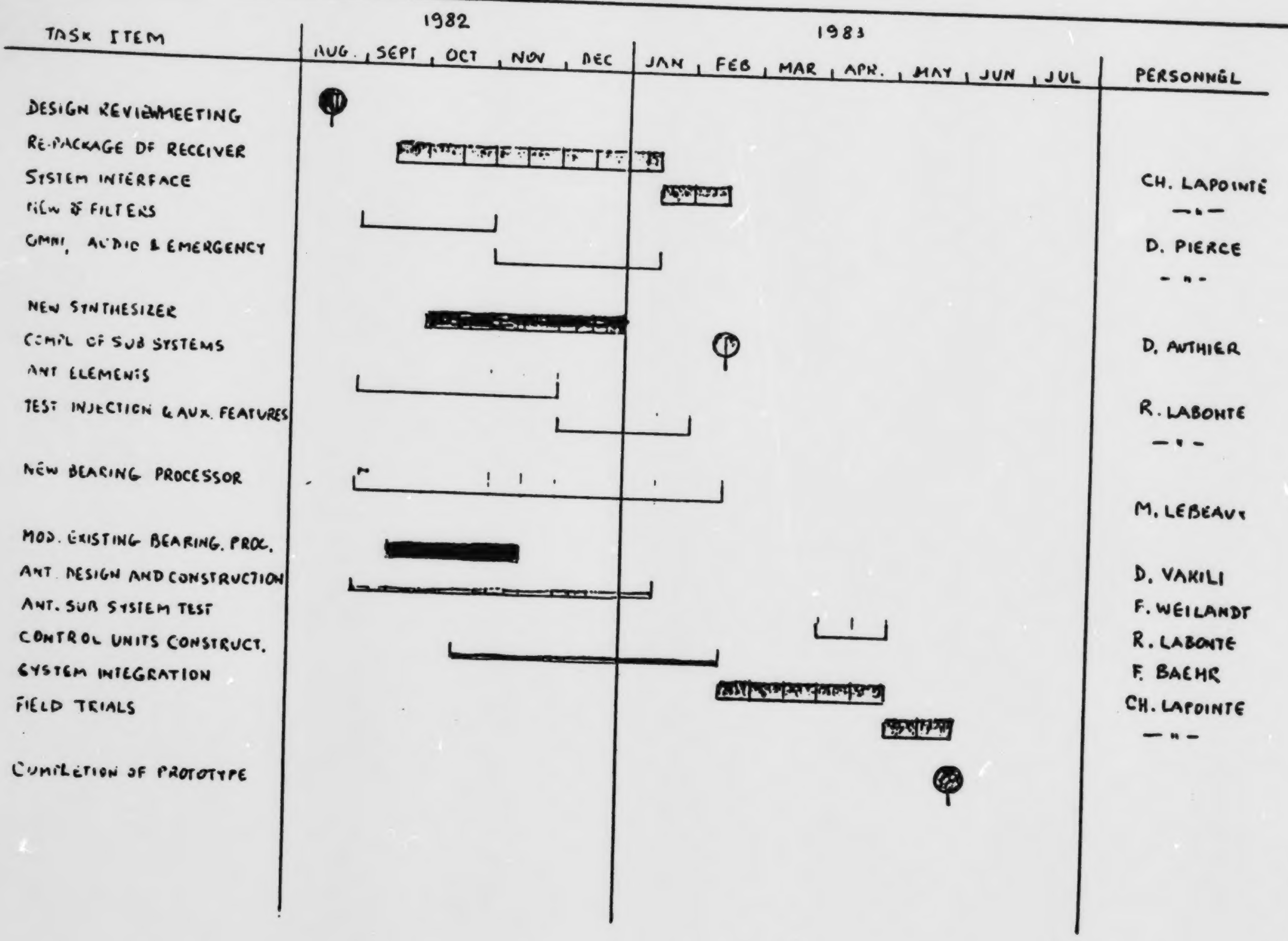
DRAFT

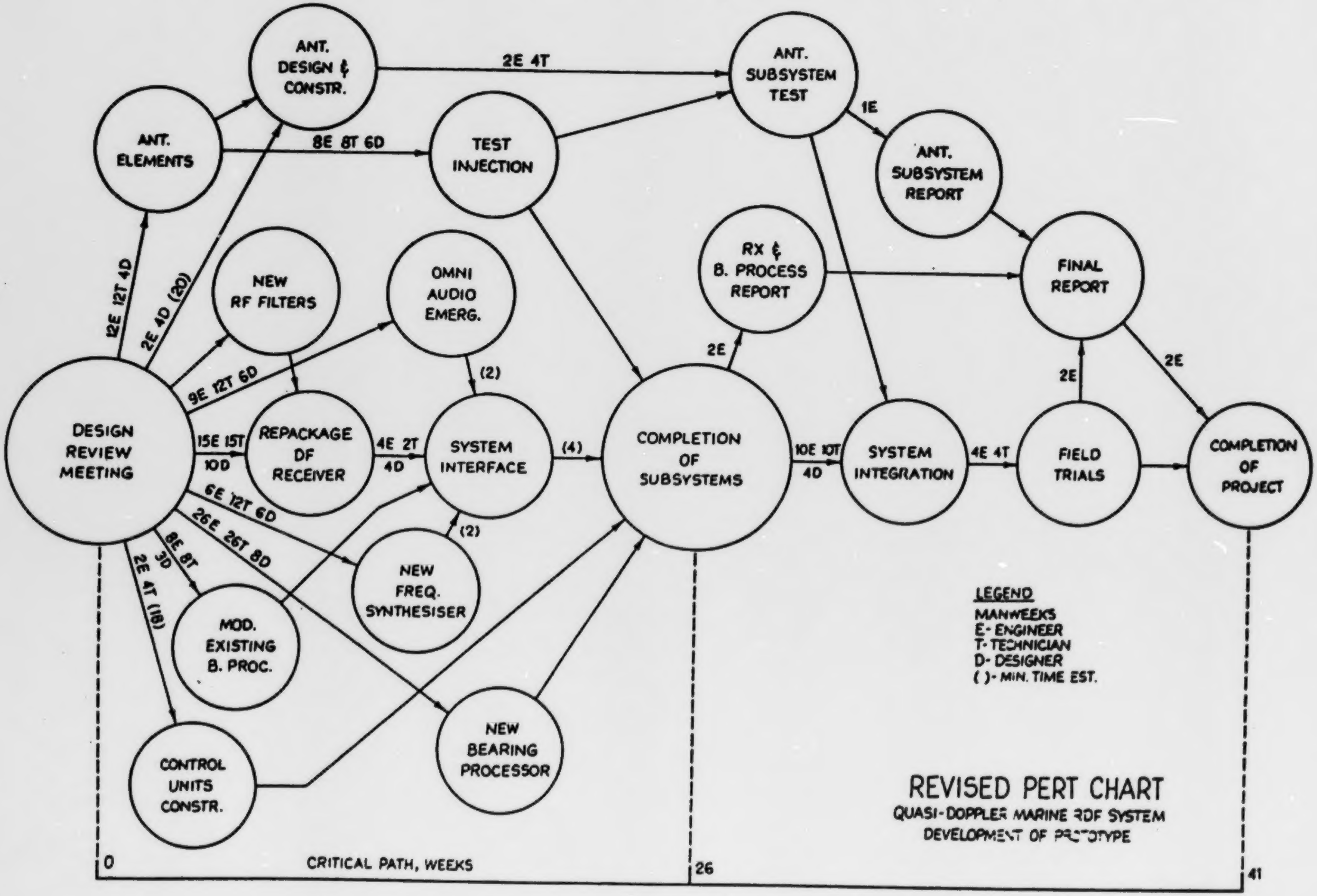
July 19, 1982
ZAK/jlm

TASK SUMMARY - DOPPLER DF

TASK ITEM	TIME (W)				REQUIRED FOR	
	E	T	D		ATC	MARINE
Re-package DF Receiver (5 modules) (RF front end, 2nd Conv. & Final IF, Phase Detector and AFC)	15	15	10	Ch.L.	✓	✓
Re-design Omni, Audio and Emergency (Basically 3 units - new approach for emergency Rx - Design FM det.)	9	12	6	D.P	✓	✓
Develop new RF filters (To be included in RF front end, LO, distribution and Omni module)	4	8	4	D.P.		✓
Develop new Synthesizer (New VCO to cover marine band plus re-program channel selection)	6	12.	6	D.A.		✓
Develop new Antenna elements (For the new frequency band, test impedance and interaction)	12	12	4	R.L.		✓
Develop new Bearing Processor	26	26	8	M.L.		✓
- in parallel modify existing bearing processor to 32 elements, possibly change scan speed and manner of averaging.	8	8	3	D.V.		✓
Improve System Interfacing (include power consumption)	4	2	4	Ch.L.	✓	✓
Test Injection and Aux. features (re-design if required)	8	8	6	R.L.	✓	✓
Antenna Sub-system test show amplitude and phase patterns	2	4		R.L.		✓
Overall System integration and Test applies to operation on rotary mast to determine DF accuracy, etc.	14	14	4	Ch.L.		✓
Antenna design and construction	2		4	F.W.		✓
Control Units	2	4		F.B.		✓
Not incl. environmental testing, etc., manuals, test procedures, reports	112	125	59			

TASK SUMMARY - ENGINEERING, DOPPLER DF.




DESIGN REVIEW MEETING
ANT. ELEMENTS
ANT. DESIGN & CONSTR.
NEW RF FILTERS
OMNI AUDIO EMERG.
REPACKAGE DF RECEIVER
SYSTEM INTERFACE
NEW FREQ. SYNTHESISER
MOD. EXISTING B. PROC.
CONTROL UNITS CONSTR.
NEW BEARING PROCESSOR
TEST INJECTION
COMPLETION OF SUBSYSTEMS
ANT. SUBSYSTEM TEST
ANT. SUBSYSTEM REPORT
RX & B. PROCESS REPORT
SYSTEM INTEGRATION
FINAL REPORT
FIELD TRIALS
COMPLETION OF PROJECT
12E 12T 4D
2E 4D (20)
9E 12T 6D
15E 15T
10D
6E 12T 6D
26E 26T 8D
8E 8T
3D
2E 4T (18)
8E 8T 6D
2E 4T
4E 2T
4D
(2)
(2)
(4)
2E
1E
10E 10T
4D
4E 4T
2E
2E
CRITICAL PATH, WEEKS
0
26
41
LEGEND
MANWEEKS
E- ENGINEER
T- TECHNICIAN
D- DESIGNER
( )- MIN. TIME EST.

REVISED PERT CHART
QUASI-DOPPLER MARINE RDF SYSTEM
DEVELOPMENT OF PROTOTYPE

3. **REVISED CASH FLOW**

The contract specifies four milestone phases of development and testing of the Quasi Doppler Marine Direction Finder.

Phase 1

To define the specific requirements of the DF system for coastal navigation and to design the system in detail sufficient to specify interface data for individual units or modules. To delineate additional R & D necessary.

To develop circuits and design packaging necessary to demonstrate the feasibility of the Marine system.

To prepare a limited list of long lead items for a complete marine system and to place orders in anticipation of the release of order.

To obtain release of order for the configuration of a complete marine prototype.

Phase 2

To develop antenna r.f. front end and frequency synthesizer to adapt the system to marine frequencies.

To implement design changes in the control/display interface in accordance with the requirements of the Coast Guard Statement of Work dated November 24, 1978.

To construct a working prototype of the marine system.

Phase 3

To troubleshoot and to test the prototype of system units, and to carry out the necessary modifications to achieve the specification targets.

To carry out system tests on the overall DF system, including electrical pe formance, temperature, humidity and field trials.

To modify the equipment and to continue updating documentation as required to achieve acceptable performance.

Phase 4

To prepare final reports on the project including equipment and system test results.

To prepare a draft manual including descriptions of circuits and operation procedures.

To prepare final engineering drawings for the project.

To refurbish the prototype incorporating corrections introduced in Phase 3.

The original cash flow envisaged on expenditure of $221,114 over a period of 50 weeks terminating November 1982.

With the completion of Phase 1, in January 1982, development of the marine system was put on a virtual hold awaiting completion of the ATC system, since the marine system is, in effect, an ongoing development of the ATC incorporating many of the features of this system.

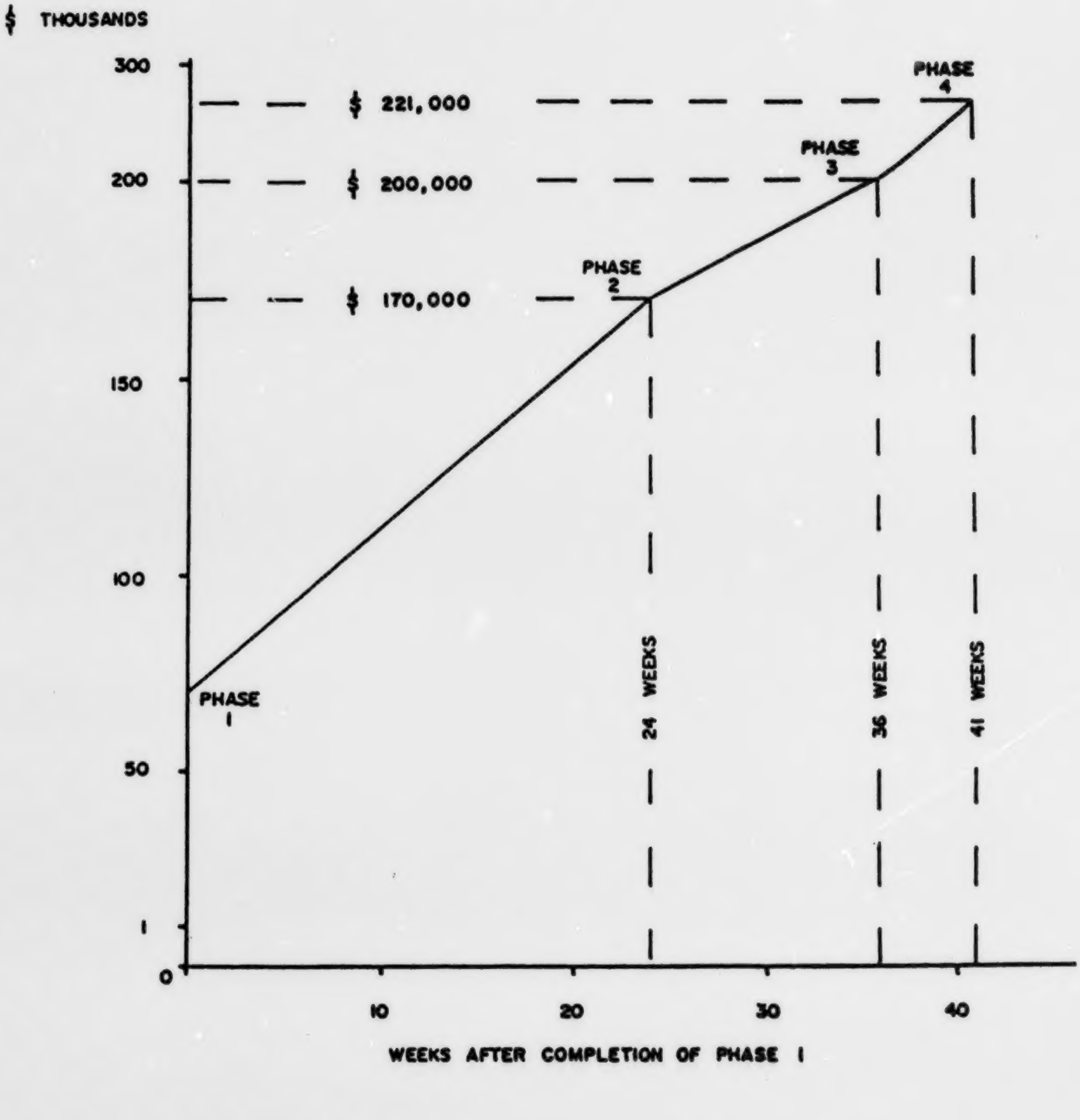
With recognition of this semi hiatus, a revi ed cash flow, based on the revised PERT chart has been formulated. The graph indicates the completion of Phase 1 as zero weeks with Phase II completed in 24 weeks, Phase III in 36 weeks to finalization of Phase IV in 41 weeks.

Phase II incurs an expenditure of $100,000 for a total of $170,000.

Phase III incurs an expenditure of $30,000 for a total of $200,000.

Phase II incurs an expenditure of $21,000 for a total of $221,000

REVISED CUMULATIVE COST CHART



QUASI. DOPPLER MARINE RDF SYSTEM

4) **Revised Marine Doppler DF Specifications**

The TDC of the Department of Transport have requested that Bayly Engineering Limited provide them with the technical specification appertaining to the Marine Doppler DF system to be designed, developed and produced by the company (DSS Contract No. 12ST.T8200-1-1515 Bayly Engineering W.O. 290006)

The technical specification appears below, following in format the technical specification of the ATC Doppler DF system.

1. **DF SYSTEM**

Frequency Range : 156-164 MHz (marine navigation)

Principle of Operation : Large aperture quasi-doppler with differential smapling

System Accuracy : ≤.5° with 32 dipole elements RMS value

RF Noise Figure : ≤7 dB

Polarization Error : Approx. 1° with 45° antenna tilt

System Sensitivity (vertical polarization) : ≤3 μV/m for ±1° accuracy

Antenna Immunity to Reflecting as compared to Adcock DF : Minimum 16 times improvement with 32 dipole elements

Group Delay Error : Cancelled out

Antenna Scanning Frequency : Adjustable to ±10% of scanning frequency to clear interference flicker

DF Receiver Phase Match Error : Cancelled out by channel commutation

Mode of Operation : Continuous, unattended

Number of Frequency Channels : Standard unit with 10 pre-set channels, each channel frequency programmable within the equipment and displayed at the remote unit to acknowledge the channel selection of the receiver. The channel selection will be indicated by a lamp over the selection keys.

An optional unit with 720 channels directly accessible with 10 programmable, 10 pre-set ones as for the standard unit. The channel frequency shall be displayed on a separate display unit after acknowledgement by the receiver.

Channel Spacing : 25 kHz

Acceptance Bandwidth : Approx. ±40 ppm of the carrier frequency

Adjacent Channel Breakthrough (25 kHz adjacent channel) : ≤1° error with adjacent channel signal up to 50 dB above wanted signal, but not exceeding 3 mV/m.

Bearing Indication : A circular analog display with LED indicators at 5° intervals plus 4 digits with 19 mm high LED numerals at the centre, blanking out at no signal and under signal overhead condition, unless connected to the store. Provided at both local and remote units.

Frequency Indication : For the 720 channel option - 7 digit LED numerals provided at both local and remote unit.

Sense Indication : QDR or QDM selectable from control panel and indicated below bearing data.

Response Time : 100 ms to 800 ms depending on the signal strength and setting of integration constant.

Bearing Reading Update : Equal to integration constant.

Valid Display Indicator: : On local control unit - blank out

Local Panel Controls	: Power on/off with indicator : Dimmer(bearing and channel display only) : Lamp test : Channel Select (pushbutton) with lamp indicating selected frequency : QDM/QDR : Integration (4 positions) : Store on/off with indicator : Remote Control indicator : System alarm indicator with audio signal : Signal overhead indicator with audio signal : Scan frequency
Remote Panel Controls	: Power on/off with indicator : Local/remote switch and indicator : Squelch on/off : Channel frequency indicator and manual override channel : Selector channel balance
Auxiliary Data Output	: At both local and remote units. TTL compatible parallel data bit format
Auxiliary Channel Select	: At the remote unit for control from another site.
Squelch Threshold	: Fully adjustable from front panel of remote unit.
Service Telephone	: Jacks provided for 2-way communications between remote and local units (audio channel disabled)
Aircraft Warning Sight (obstruction lights)	: Integrated with antenna structure (may be left out if not required)

Cables

Antenna Head to Remote Receiver	: 2 coaxial double shielded ¼" and 1 multicore, 50 m max. RF Connectors "N" type
Remote to Local Short Distance Option	: 4 wire telephone line - 10 km max. Multicore cable - 100 m max.

2. MULTIPLE CONTROL STATION OPTION

Multiple Control Station	: Two or more local panel controls can be interconnected by switching at the 4 wire telephone line level.

3. AUDIO MONITORING OPTION

Monitor Antenna	:	Centre of the array
Frequency	:	Automatically tuned with the DF system
Tuning	:	156-164 MHz
Receiver Noise Factor	:	≤7 dB
Receiver Sensitivity	:	(S + N)/N capability of ≤12 dB with RF input modulation m = 30% at 1 kHz with audio level adjusted to give 50% of rated audio power output.
Type of Detection Option	:	AM or FM selectable on the remote unit
	:	Either AM or FM as requested
Output	:	0.5W outputs on both remote and local units, provided with on/off switches
Auxiliary Output	:	50 mW at 600Ω on the local unit.
Squelch	:	Provided on the remote unit to mute the receiver output until carrier imports of: 1) at maximum, not less than 50 μV/m 2) at minimum, more than 5 μV/m are applied under the service conditions specified.
	:	The squelch circuit shall be immune to noise. The ratio of signal intensities necessary to open and close the squelch shall not exceed 0.5 to 1.
AGC	:	Provided on the remote unit.
Volume Control	:	Individual with each loudspeaker

Additional Cables

Antenna Head to Remote Receiver	:	Coaxial, double shielded ¼" 50 m max. "N" type connectors

4. EMERGENCY CALL OPTION

Antenna : Common with audio monitoring provided with separate filter.

Receiver NF : ≤7 dB

Tuning : Set at channel #15, 156-375 MHz

AGC : Preset

Detector (warning to operator) : Carrier presence above threshold preset at the remote unit.

Additional Controls

Auto-Man (156-375 MHz emergency override) : At both local and remote units

Alarm : LED indicators at local and remote units operational only when the bearing indicator is dedicated to the emergency signal bearing.

Additional Cables

Antenna Head to Remote Receiver : Coaxial double shielded ½", 50 m max. ("N" type connectors)

5. ANTENNA SIMULATOR OPTION

Antenna Simulator : Provide selection of 4 simulated targets at 45°, 135°, 225° and 270° locations

RF Test Source : Generate a synthetic RF signal by adding i.f. to the L.O. frequency

Location : In the antenna head (preferred)

Control : Pushbutton from local unit (Note: normal operation is disengaged when operating the antenna simulator)

Environment

Operational Temperature Range (antenna) : -55°C to +55°C

Operational Temperature Range (local and remote unit) : -20°C to +55°C

Humidity : 95% max.

Wind Load (antenna) : 176 km/hr max.

Salt Spray (antenna) : Guidance according to MIL specifications.

Ice Loading : 5 cm max. (1.968")

Antenna Height : Antenna centre up to 60 ft. above ground.

COMPLIANCE SPECIFICATIONS

In related compliance specifications, the project will be undertaken by virtue of guidance according to MIL specifications.

Antenna structure in accordance to CSA S37-1976 specification.

5. LONG LEAD ITEMS

Contract DSS #12ST.T8200-1-1515 "To Develop and Test a Prototype Quasi-Doppler Marine UHF Radio Direction Finder" was let on June 12, 1981 with a completion date of November 1982.

As previously stated, this contract completion is dependent upon the progress of the ATC Doppler. With this proviso, a Pert Chart was drawn up indicating the Marine Doppler system could be completed in 52 weeks, with the final evaluation report available in 40 weeks.

The results of the evaluation of the ATC system at Granby would decide the starting date of the marine system. This evaluation was scheduled in January 1982. The 40 week period would terminate during the first week in November.

In order that this date could be met, it was indicated in the Pert Chart that long lead items should be ordered immediately.

Due to the high cost of holding inventory, manufacturers have made a concerted effort to reduce the quantity of their normal, in-stock, components and material. Instead of being able to order catalog items from "off the shelf" it is now necessary to wait until the next batch is produced.

When the first phase of inventory reduction was undertaken, the manufacturer would start the production cycle with 50% orders in-house with the expectation that, with production underway, the remaining 50% of orders would be in-house.

With the present economic climate, a high percentage of component manufacturers will only produce when they have 100% of the orders in-house.

These conditions have led to situations where it is not unusual to be given a 12 month delivery date for specialized items.

In order to mitigate this problem, long lead items have been ordered well before their projected usage. To meet the development schedule of the marine doppler DF system, it was considered essential that conformed components and material be ordered as soon as possible. Such ordering commenced in January 1982.

SPECIFIC LIST

Based on delays encountered during procurement of the ATC system, the following items were considered necessary to order as far in advance as practicable. Only items confirmed as being not subject to change are on this list.

1. Type RG214 Double Shielded low loss ½" coaxial cable
   - projected delivery 6 months

2. Type RG302/V Semi-rigid 494 coaxial cable
   - projected delivery 4 months

3. Type TNC plugs for above cables
   - delivery 4 months

4. Type N plugs for above cables
   - delivery 4 months

5. Trimmer Capacitors
   - delivery 4 months

6. Sundry IC's (14 different types)
   - up to 4 months

7. Power Supplies
   - 3 months

8. Close Tolerance Capacitors

- 4 months

9. Sundry Miniature Switches

- up to 3 months

10. Sundry close tolerance Quartz Crystals and Filters

- up to 5 months

11. Type SMA connectors for semi-rigid coaxial cable

- 3 months

6) Statement Concerning Tests Conducted at Granby, Jan. 1982

During the period of January 12th to January 19th, 1982, a series of tests were undertaken to ascertain the practicability and feasibility of the ATC System, thus terminating the R & D contract.

The ATC System tests proved the Direction Finding capabilities and accuracy to be in accordance with the specification, hence confirming the feasibility of the system.

These tests were not fully comprehensive since to achieve this level of acceptance necessitated field trials under actual flying conditions.

It was therefore, understood that continuing tests would be undertaken at Kingston Airport, Kingston Ontario.

Nevertheless, the level of tests conducted in Granby achieved the objective of demonstrating the feasibility of a Marine Quasi-Doppler RDF System and the results obtained were sufficiently advanced to permit TDC (Mr. T. Rudback) to authorize the start of the main Marine Development on February 1, 1982.

References

1. Development and Construction of a Quasi-Doppler Marine VHF Radio Direction Finder. June 20, 1981, Z.A. Krajewski.

2. Statement of Work for Development-Doppler Radio Direction Finder (Draft September 15, 1978).

3. Contract D55 12ST.T8200-1-1515
To Develop and Test a Prototype Quasi-Doppler Marine VHF Radio Direction Finder.

4. T.D.C. Work Statement Quasi-Doppler Marine VHF Radio Direction Finder. June 12, 1981.

5. Development, Design, Construction and Testing of a Prototype Doppler Radio Direction Finder (ATC) Final Progress Report No. 13. February 2, 1981.

6. Development, Design, construction and Testing of a Quasi-Doppler Radio Direction Finder (Marine) Status Report 1982, W. Jones.

7. Development, Design, Construction and Testing of a Quasi-Doppler Radio Direction Finder (ATC) Final Report 1982, Z.A. Krajewski.

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a member of the
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DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 2

For Period February 1, 1982
To August 24, 1982

DSS File No. 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

BY: W. Jones
Project Co-ordinator

Distribution

TDC (5)
Science Procurement Manager (1)
TC, Telcom and Electronics Branch (1)

BAYLY
ENGINEERING
LIMITED

AEG
a member of the
AEG TELEFUNKEN group

August 24, 1982
WJ/kad

1. SCOPE

This is the second progress report on the development of the Quasi-Doppler RDF System for Marine purposes, covering the period from February 1, 1982 to August 24, 1982. It is the first report to deal with Phase II of the contract, i.e. to construct a working prototype of the Marine System.

2. CURRENT STATUS

During the reporting period, preliminary work has been undertaken, specifically the design of the 32 dipole antenna which is at the 90% completion level.

At the same time, procurement of long lead items was undertaken. This is now complete with approximately $32,000 of components in inventory.

Preparation work was instituted resulting in the completion of the technical specification for the Marine System to be submitted at the Critical Design Review meeting.

3. PERSONNEL

The project team involved in the development of the Marine System is constituted as follows:

Systems Engineer	Z.A. Krajewski	Ajax
Mechanical Engineer	F. Weilandt	Ajax
Reciever Designer	C. Lapointe	Granby
Antenna (electrical)	R. Labonte	Granby
Signal Processing	D. Vakili	Ajax
	F. Baehr	Ajax

RF Filters, Omni, Audio Emergency	D. Pierce	Ajax
Frequency Synthesizer	D. Authier	Granby
Beaning Processor	M. Lebeau	Granby
Documentation	R. Beck	Ajax
Contracts Adminstrator	E. Mann	Ajax
Project Co-ordinator	W. Jones	Ajax

4. WORK IN PROCESS

The above project team is the same as engaged in the ATC project. Consequently, improvements have been included in the ATC to accomodate certain Marine requirements.

This work is not visibly evident as a specific Marine development but such developments are to be included in the Marine System prototype. In this way, continuous development for the Marine System has been undertaken during the reporting period.

5. MEETINGS

Several meetings with DOT & TDC personnel were held during this period.

The next meeting is scheduled for August 25th & 26th, the results of which will be included in Progress Report No. 3.

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DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 3

For the Period August 24, 1982
to September 24, 1982

DSS File No. 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

By: W. Jones
Project Co-ordinator

Distribution:

TDC (5)
Science Procurement Manager (1)
TC, Telcom and Electronics Branch (1)

1. Scope

This is the third progress report on the development of the Quasi-Doppler RDF System for Marine purposes, covering the period from August 24, 1982 to September 24, 1982. It deals with a series of in house meetings together with the meeting (TDC) held in Montreal August 25/26, 1982. Progress is reported as a result of these meetings.

2. Meetings

(a) TDC August 25/26, 1982, Montreal.

In attendance from Bayly were G. Krajewski, F. Weilandt and W. Jones. Reference Transport Canada TDC minutes September 16, 1982. (Mr. N.E. Rudback)

Matters arising from the minutes:

1 - New cash flow chart implemented
2 - Progress Report #2 filed
3 - Awaiting Coast Guard approval
4 - Still in preparation (3 sets ATC drawings filed)
5 - In process
6 - O.K.
7 - Noted
8 - Noted
9 - In process
10 - Noted
11 - Noted
12 - Filed Sept. 24, 1982

(b) Granby September 13/14, 1982. Bayly/Granby personnel.

The purpose of this meeting was to acquaint & familiarize Granby personnel with the results of the above Montreal meeting. Discussion was held re plant loading to agree with PERT projections.

(C) Ajax September 20/21, 1982. Ajax/Granby personnel.
This meeting was convened for detailed planning of the project. Among items discussed were specifications, discussion of responsibilities between Ajax & Granby, PERT chart, release for production of sub-assemblies etc.

3. Current Status

As a result of the above meetings, release to manufacture a number of PCB's has been given together with the fabrication of the 32 dipole antenna. Other PCB's are being finalized for production. Instructions have been given to undertake design specifications for the new or modified boards.

4. Personnel

As indicated in Progress Report #2 with the exception of D.A. Pierce, who has left the employ of the company. The sub-project which was his responsibility has been allocated to Granby under the jurisdiction of R. Labonte.

5. Work in Process

Purchasing of non-long dated components and material has now been undertaken. That material already in inventory i.e. long dated items, is being allocated to Granby and Ajax where appropriate.

Various reports and submissions arising out of meetings are being compiled and finalized.

Jones

JONES

DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 4

For The Period September 24, 1982

To October 31, 1982

DSS File No. 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

BY: W. Jones
Project Coordinator

Distribution:

TDC (5)
Science Procurement Manager (1)

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1. Scope

This is the fourth progress report on the development of the Quasi-Doppler RDF System for Marine purposes, covering the period from September 24th to October 31, 1982. It deals primarily with the preliminary work being undertaken at this time.

2. Matters Arising from Progress Report #3

All matters reported under Para. 2(a) have been excuted with the exception of (3) awaiting Coast Guard approval. This is related to the technical specification submitted by Bayly on October 13, 1982.

3. Current Status

Refering to the SPEC flow chart #82-7420-503 ½ the following blocks have been completed.

A4
B4
C4
B6
D6
E7
E9
J2
H3

The following blocks are partially complete and in process:

C7
D7
F7
L7

The following blocks are awaiting government implementation:

J3
M3
P3
K3
J5
M4
M5
P5
R5
J6
N6
P6
R6

Complete inventory and allocation of procured components has been implemented to allow purchase order placement of those components not classified as long delivery items.

Personnel

There has been no change in personnel since Progress Report #3.

General

The project has and is proceeding at a controlled rate until such time as certain contractual changes, i.e. those contained in the "no action" blocks have been defined.

W. Jones

W. JONES

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DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 5

For The Period October 31, 1982

To November 30, 1982

DSS FILE NO. 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

Distribution

TDC (5)
Science Procurement Manager (1)

BY W. Jones
Project Co-ordinator

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1. SCOPE

This is the fifth progress report on the development of the Quasi-Doppler RDF system for Marine purposes covering the period from October 31, 1982 to November 30, 1982.

2. MATTERS ARISING FROM PROGRESS REPORT #4

As per para. 2 of that report, approval of the technical specification by the Coast Guard is still outstanding.

Also outstanding, is the implementation of the SPEC flow chart #82-7420-503½ blocks.

J3	R3	M5	J6	R6
M3	J5	P5	N6	
P3	M4	R5	P6	

3. CURRENT STATUS

In addition to work in process on blocks C7, F7, D7, L7 of the SPEC chart, work has commenced on blocks M7, P7, and R7.

As stated in Progress Report #4, the project is being processed at a controlled rate awaiting contractual clarification.

PERSONNEL

Mr. Darius Vakili has left the employ of the company but has been retained as consultant. He has been replaced by Mr. Welston Ng.

GENERAL

The project is sufficiently advanced to commence immediate construction upon implementation of contractual modifications.

W. Jones

W. JONES

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DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO
DIRECTION FINDER

Progress Report No. 6

For The Period, November 30, 1982

To December 31, 1982

DSS File No. 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

Distribution

TDC (5)
Science Procurement Manager (1)

BY: W. Jones
Project Co-ordinator

BAYLY
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1. Scope

This is the sixth progress report on the development of the Quasi-Doppler RDF system for Marine purposes, covering the period from November 30, 1982 to December 31, 1982.

2. Matters Arising from Progress Report #5

Those items stated to be outstanding in Report #5 remain as such.

3. Current Status

Generally, work in process is confined to finalizing the procurement cycle of the #7 series blocks of the SPEC chart.

In addition, the frequency synthesizer (blocks L7, 8, 9 & 10) has been implemented. The synthesizer design and construction was sub-contracted in March 1982. This unit has now been received and is undergoing acceptance tests.

Work as indicated by block D7 and part D8 consists of the assembly and testing of quantity three (3) dipoles. These dipoles have now been tested individually and proved satisfactory. Testing is now proceeding with the ground plane and antenna simulator to measure and ascertain mutual coupling etc.

4. Personnel

There have been no changes in project personnel.

5. Contractual

Work is being undertaken, defining in more detail, the subject matter of the proposal covered by block J2 of the SPEC chart.

6. General

Apart from the items discussed above, the remainder of the project is, at the present time, in a "holding pattern".

W. Jones

W. JONES

TEST OF FREQUENCY SYNTHESIZER FOR MARINE DOPPLER (from K.D. Urbatzka)

1. Frequency setting

Range 184 MHz to 208 MHz with 25 KHz increment is covered correctly.

2. Photograph spectrum at 5 KHz/div., bottom, middle and top of range

- photos included, with original design of the synthesizer (Figures 1 to 4)
- Then, synthesizer modified as per instructions from K.D.U.

Changes are :

Component	was	replaced by
C_3	1250 pf	830 pf
C_4	1000 pf	1300 pf
C_5	2200 pf	2700 pf
$C_6//C_{44}$	6500 pf (2 x 13000 in series)	4000 pf (3900//100)
$C_9//C_{45}$	6500 pf (2 x 13000 in series)	4000 pf (3900//100)
C_{10}	1250 pf	830 pf
C_L	-	390 pf
C_K	-	390 pf

Impossible to lock below 200 MHz (184 to 200). Spurious frequency at 25 KHz from main frequency was at -65 dBc for f = 208 MHz (no change from original design)

Synthesizer was again modified to reflect the original design except that C_L and C_K were kept.

Photos were taken for bottom, middle and top of the frequency range, for 2 KHz/div and 5 KHz/div. (Figs. 5 to 10)

3. Frequency accuracy

for	reading on counter (10 sec time base)
184 MHz	183 999 999.8 Hz
196 MHz	195 999 999.8 Hz
208 MHz	207 999 999.8 Hz

/...2

4. Output level and Impedance

Freq.	Level output 1 (E7-E8)	Level output 2 (E9-E10)	Impedance output 1 (E7-E8)	Impedance output 2 (E9-E10)
184 MHz	+0.7 dBm	-0.1 dBm	56 Ω	108 Ω
196 MHz	-1.5 dBm	-2.3 dBm	85 Ω	155 Ω
208 MHz	-3.1 dBm	-4.0 dBm	101 Ω	149 Ω

5. Phase locking VS temperature

Phase locking works correctly at -20°C and + 45°C.

Noise spectrum can be seen on photograph (Figs. 10 to 22) and basically the same as at room temperature.

6. Spectrum in 0-1.2 GHz band

Photographs for three temperature ranges are included :

Fig. 23 for -20°C
Fig. 24 for 22°C
Fig. 25 for 45°C

7. Settling time for 1 MHz step (within 15 KHz)

Freq. (MHz)			Settling time (ms)
184	to	185	10
185		184	10
196		197	15
197		196	15
206		207	25
207		206	24
208		209	28
209		208	26

Test was done also for a 16 MHz step.

Freq. (MHz)			Settling time (ms)
192	to	208	45
208		192	24

(Note : settling time does not change with temperature)

7a. Variation VS power supply change (output 1 only)

		+5% (15.75 V)	-5% (14.25 V)	-10% (13.5 V)
LO1,	184 MHz	184 000 001.4 Hz	184 000 001.1 Hz	184 000 001.4 Hz
	196 MHz	196 000 001.1 Hz	196 000 001.5 Hz	196 000 001.4 Hz
	208 MHz	208 000 001.0 Hz	208 000 001.7 Hz	208 000 001.0 Hz

/...3

7a. (cont'd)

		+5% (15.75 V)	-5% (14.25 V)	-10% (13.5 V)
LO1	184 MHz	+0.8 dBm	+0.8 dBm	+0.4 dBm
level	196 MHz	-1.4 dBm	-1.4 dBm	-1.8 dBm
	208 MHz	-3.0 dBm	-3.0 dBm	-3.4 dBm
LO3	2.4 MHz	no change (2.4 MHz)		
	level	+6.4 dBm	+5.8 dBm	+5.5 dBm

8. Aux. output level

	output 1 (E4-E3)	output 2 (E2-E1)
(2.4 MHz)	+ 6.2 dBm	+ 6.2 dBm
Impedance	33 Ω	35 Ω

9. Spectrum (2KHz/div)

See Fig. 26

10. Spectrum up to the 10th harmonic

See Fig. 27 and 28.

11. Frequency accuracy

2 400 000.0 Hz (10 sec time base)

12. Power

+ 15 Volts (± 5%), 120 mA

13. Interference on power and control lines

Measurements made with high impedance probe and spectrum analyser : nothing seen on spectrum.

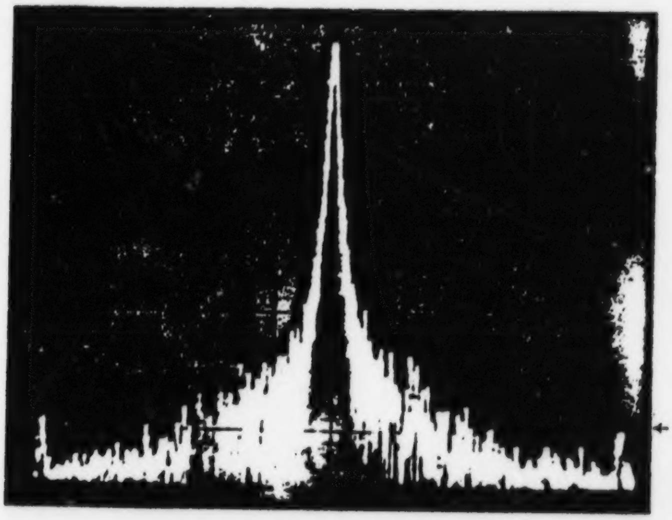
14. Test instruments used

* Freq. converter : HP5253B (Inv. # T1229)
* Counter : HP5245L (Inv. # 04902)
* Oscilloscope : Tektronix 466 (Inv. # 04951)
* Pulse generator : HP 8011A (Inv. # 04952)
* Vector Voltmeter: HP8405A (Inv. # 05338)
* Camera : HP197A (Inv. # 04912)
* Spectrum analyser : HP140T display section (Inv. # 05343)
  HP8554L RF section (Inv. # 05341)
  HP8552A IF section (Inv. # 05342)
* Power supply : HP6227B (Inv. # 04947)
* DMM : Fluke 8600A (Inv. # 04947)

/...4

REMARKS

- EPROMS are connected to + 8 Volts. EPROMS are specified by the manufacturer to work at 5 volts only.
- No details are available (drawing) to build the coils.
- Assembly drawing is missing.
- Lock indicator, ON when locked.

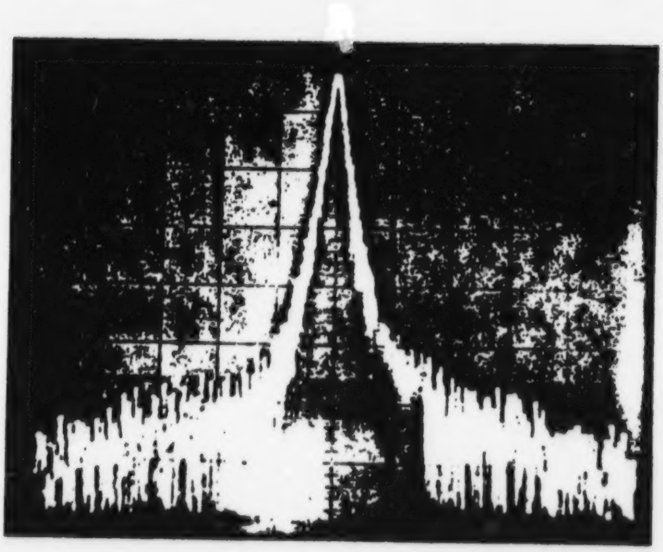


Fo = 208 MHz
BW = 0.3 KHz
SCAN W = 5 KHz/DIV
SCAN TIME = 0.1 SEC/DIV
VIDEO FILTER = 10 KHz
VERT = 10 dB/DIV

← - 65 dBc

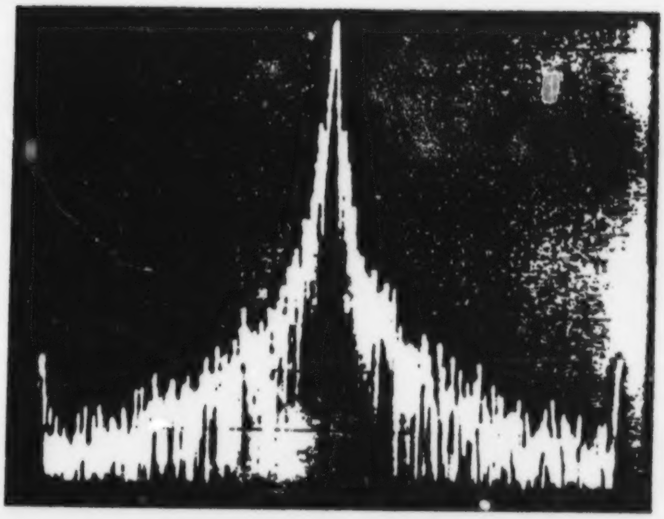
V OUT = - 5 dBm

Figure 3



Fo = 208 MHz
BW = 0.3 KHz
SCAN W = 2 KHz/DIV
SCAN TIME = 0.1 SEC/DIV
VIDEO FILTER = 10 KHz
VERT = 10 dB/DIV

Figure 4

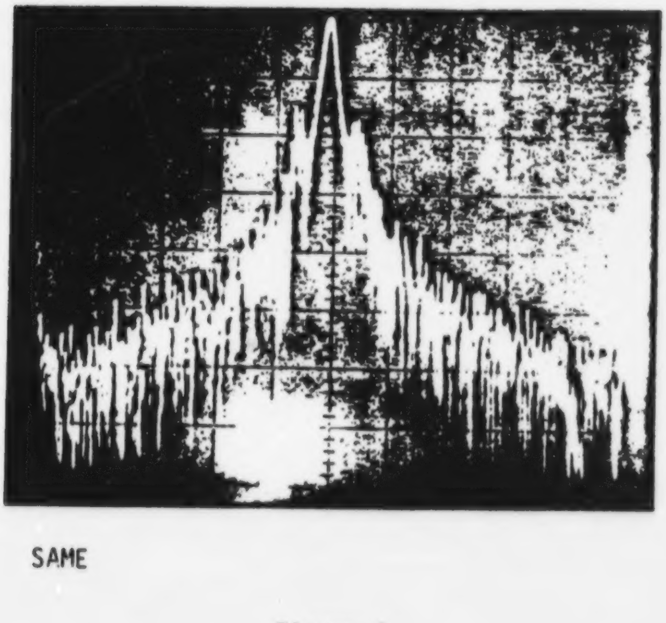


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : 0 dBm
FREQ : 184 MHz

Figure 5



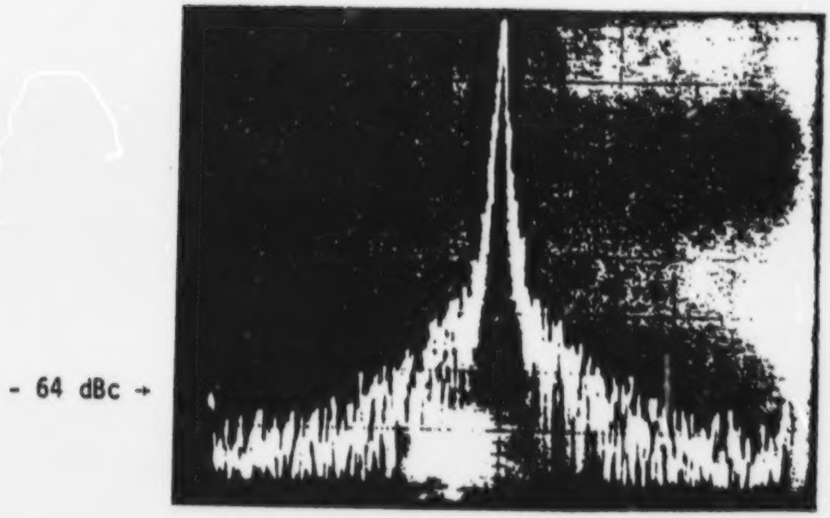
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = 22°C

Figure 6

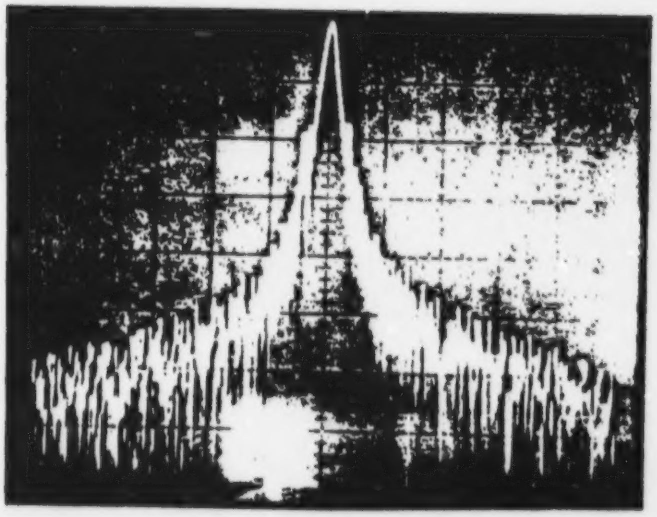


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : - 2 dBm
FREQ : 196 MHz

Figure 7



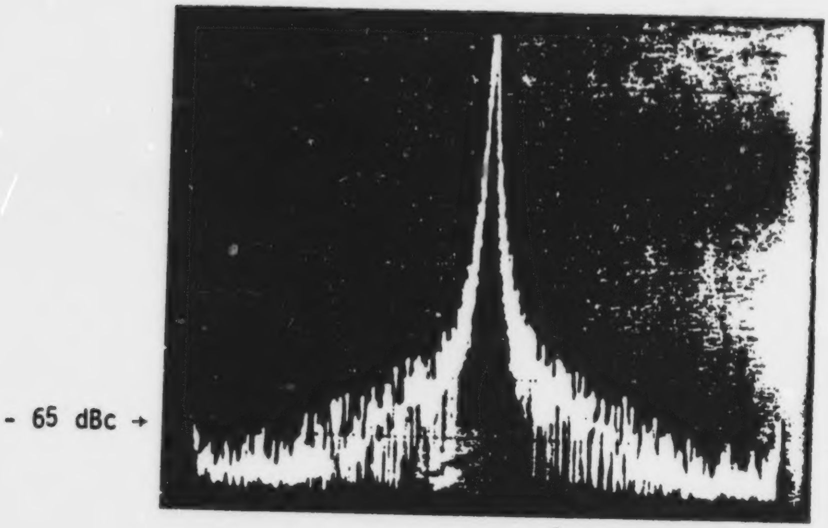
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = 22°C

Figure 8

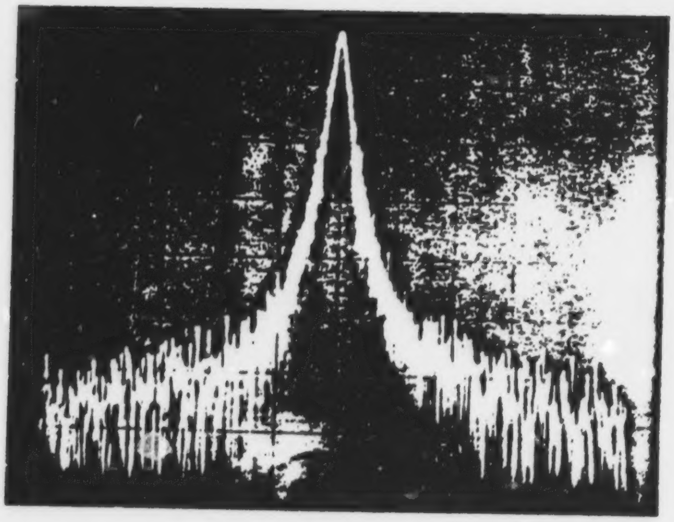


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : - 4 dBm
FREQ : 208 MHz

Figure 9



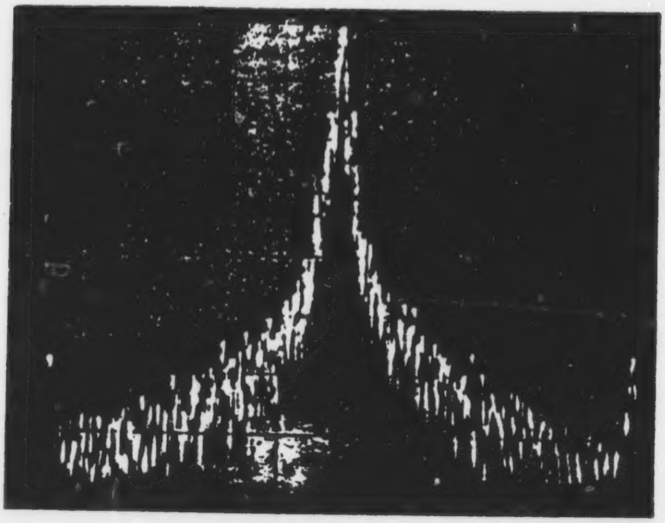
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

Figure 10

TA 22 °C



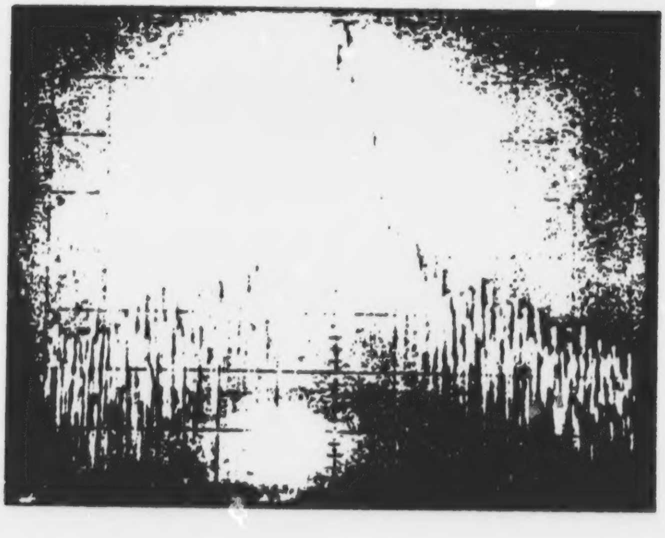
- 56 dBc →

SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : 0 dBm
FREQ : 184 MHz

Figure 11



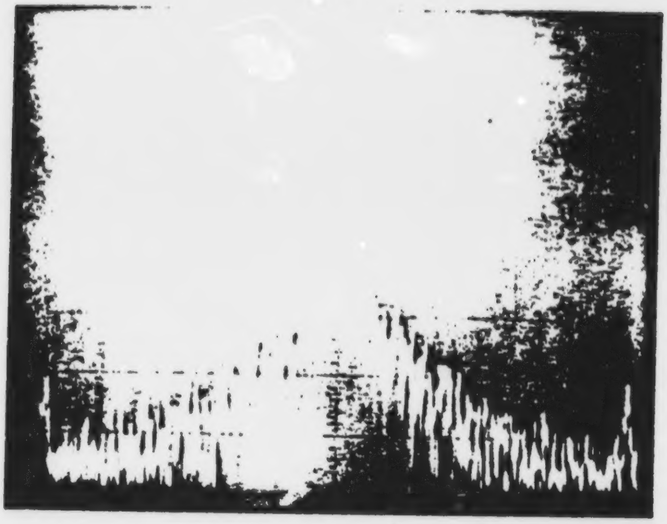
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

Figure 12

TA - - 20°C

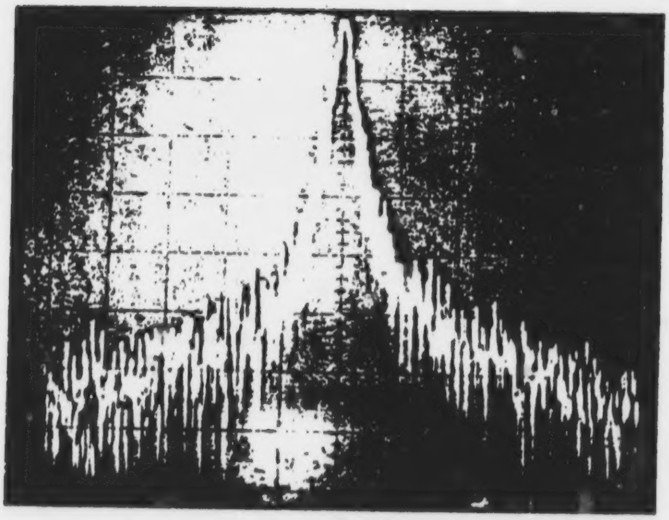


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : - 2.5 dBm
FREQ : 196 MHz

Figure 13



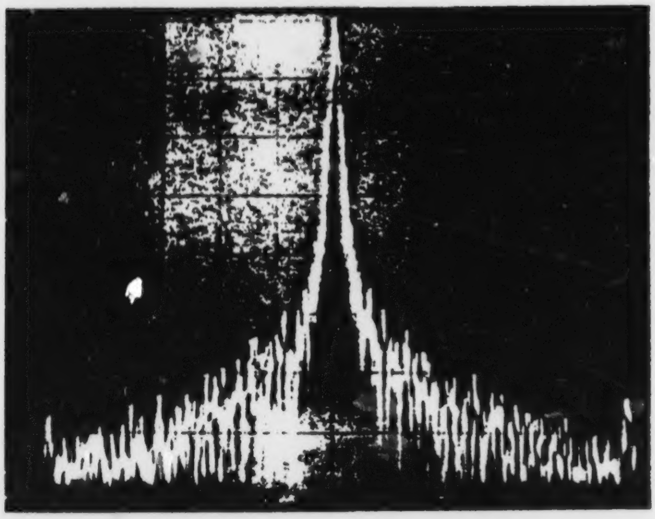
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = - 20°C

Figure 14

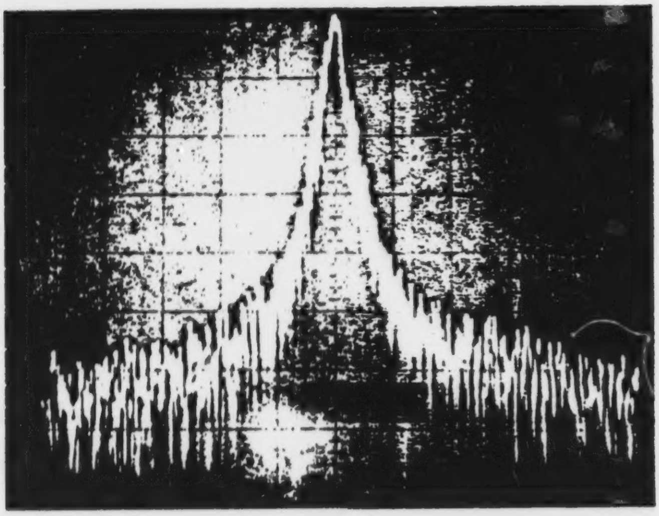


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : -4.5 dBm
FREQ : 208 MHz

Figure 15



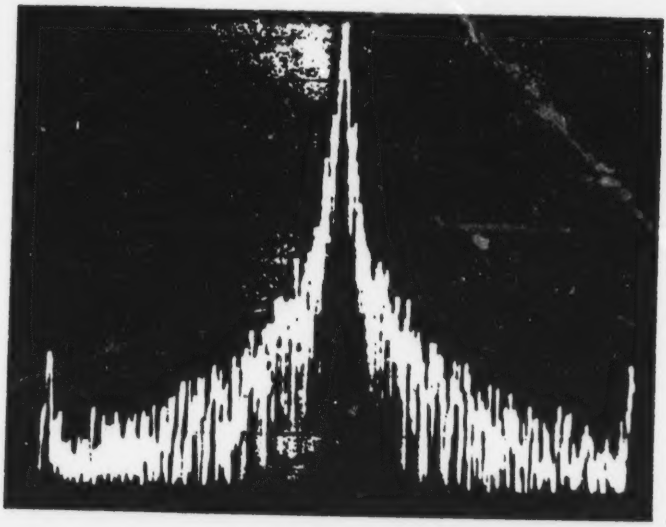
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = - 20°C

Figure 16



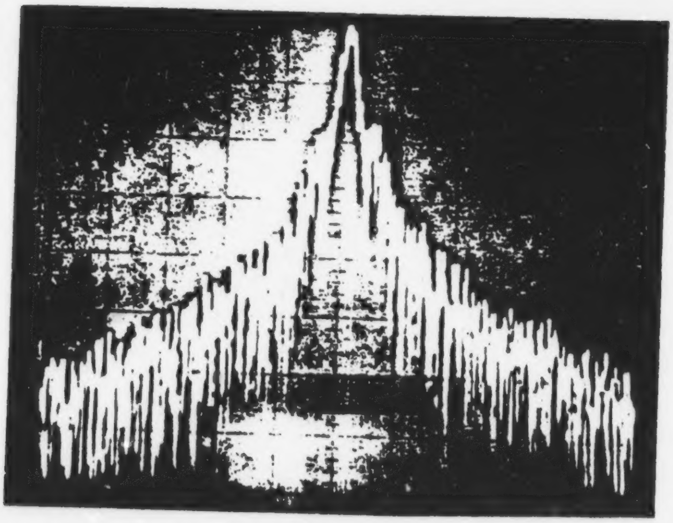
- 57 dBc →

SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : -1 dBm
FREQ : 184 MHz

Figure 17



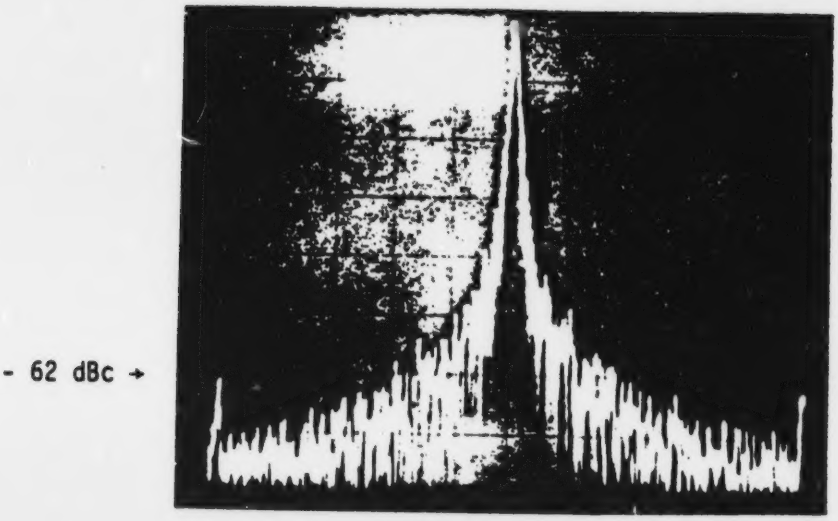
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = 45°C

Figure 18

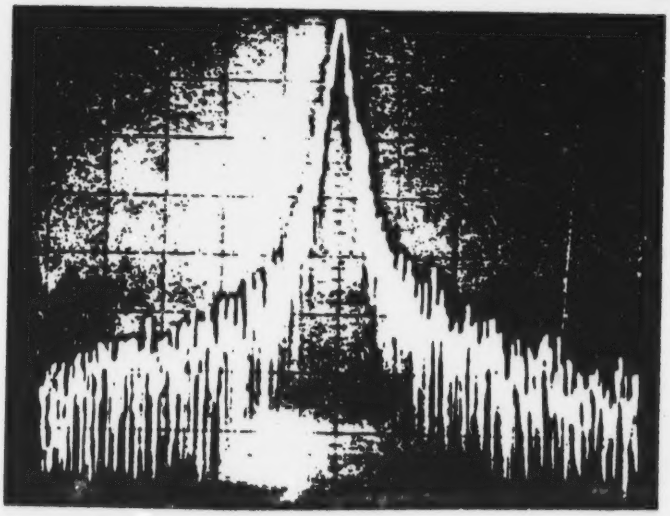


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL : - 3 dBm
FREQ. : 196 MHz

Figure 19



SAME EXCEPT :

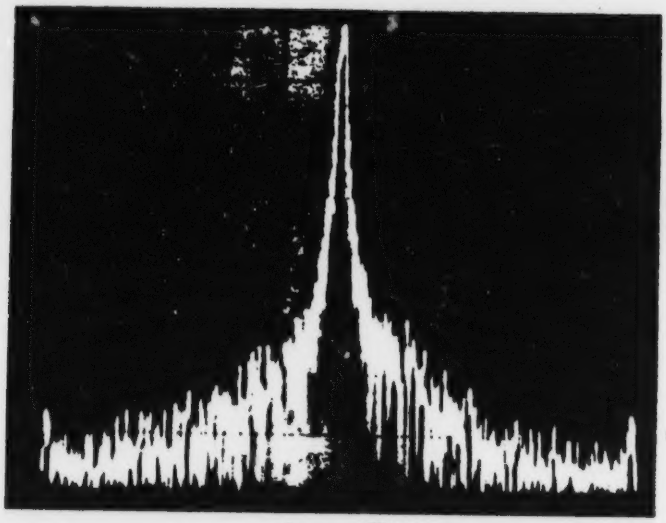
SCAN W = 2 KHz/DIV

SAME

TA = 45°C

Figure 20

- 65 dBc →

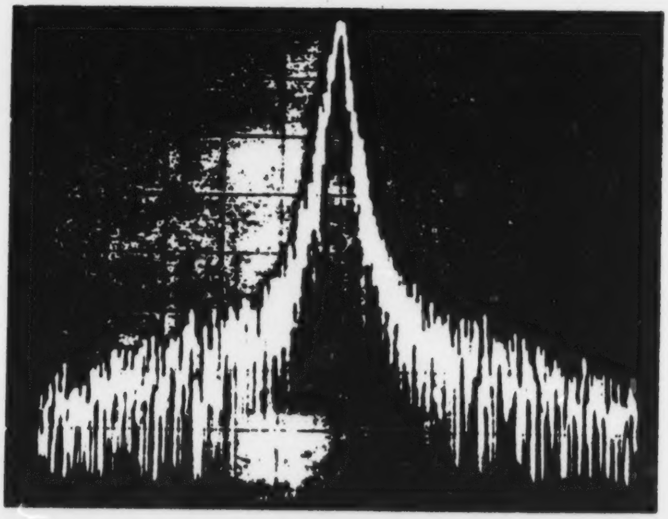


SETTINGS

BW = 0.3 KHz
SCAN W = 5 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
LEVEL - 4.5 dBm
FREQ : 208 MHz

Figure 21



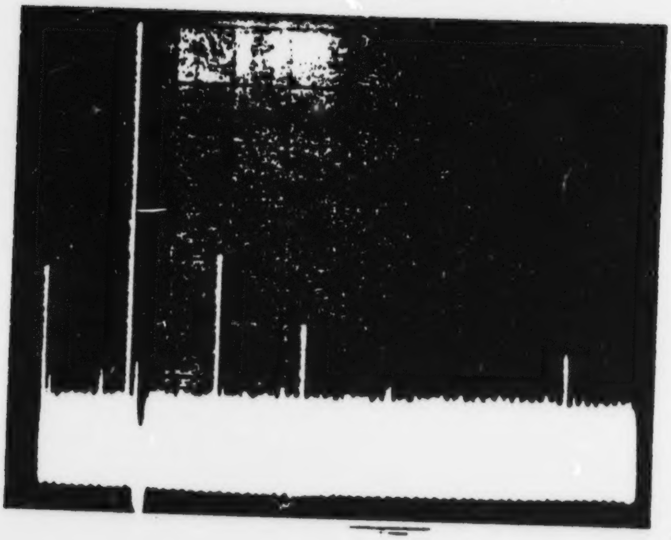
SAME EXCEPT :

SCAN W = 2 KHz/DIV

SAME

TA = 45^{o}C

Figure 22



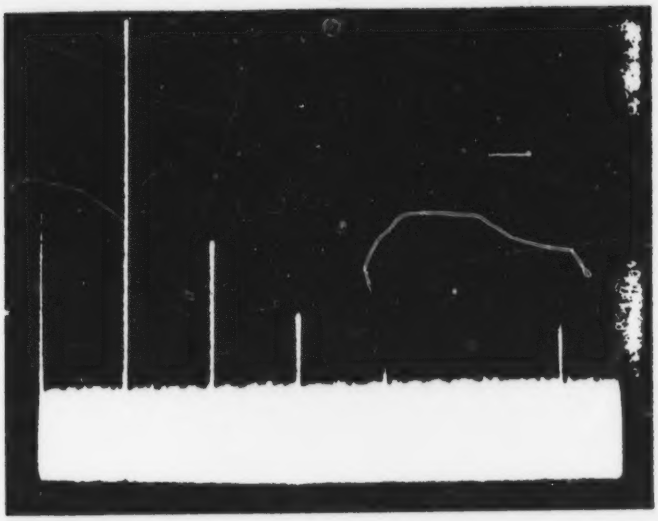
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
FREQ : 184 MHz
SWEEP : 0 to 1.2 GHz

* SAME AT LO1 = 196 MHz and LO1 = 208 MHz

TA = -20°C

Figure 23

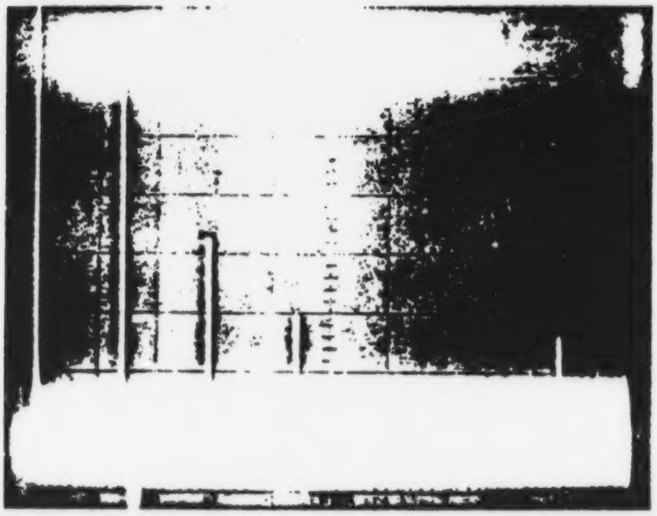


VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
FREQ: 184 MHz
SWEEP : 0 à 1.2 GHz

Same at LO1 = 196 MHz and LO1 = 208 MHz TA = 22^{o}C

Figure 24

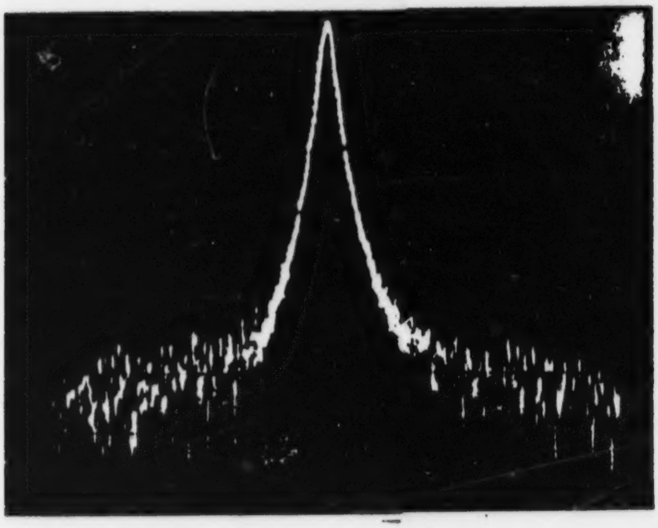


VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO1 OUT
FREQ : 184 MHz
SWEEP : 0 to 1.[illegible] GHz

* Same at LO1 = 196 MHz and LO1 = 208 MHz TA = 45°C

Figure 25

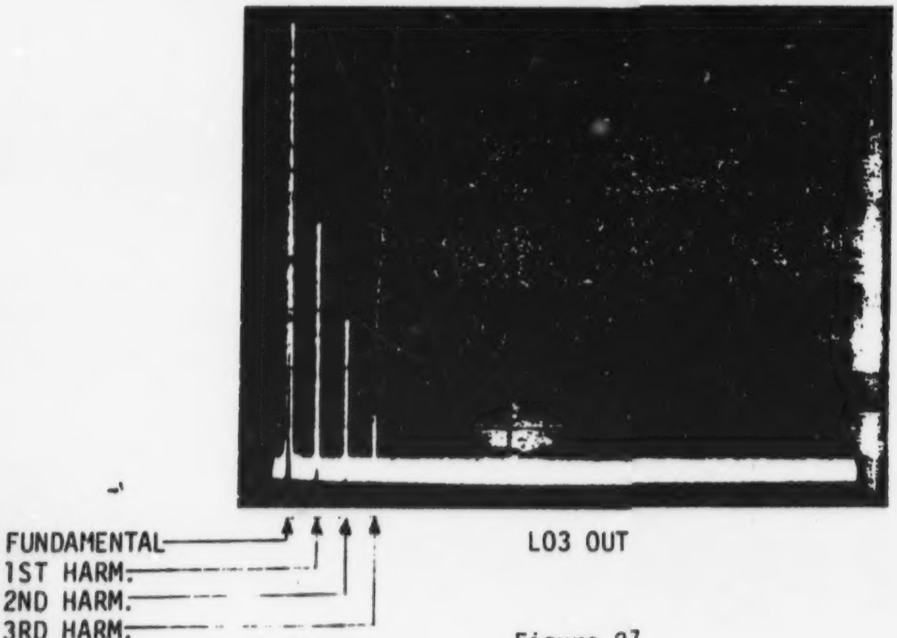


SETTINGS

BW = 0.3 KHz
SCAN W = 2 KHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO3 OUT
LEVEL: 7 dBm
FREQ : 2,400,000 Hz

Figure 26



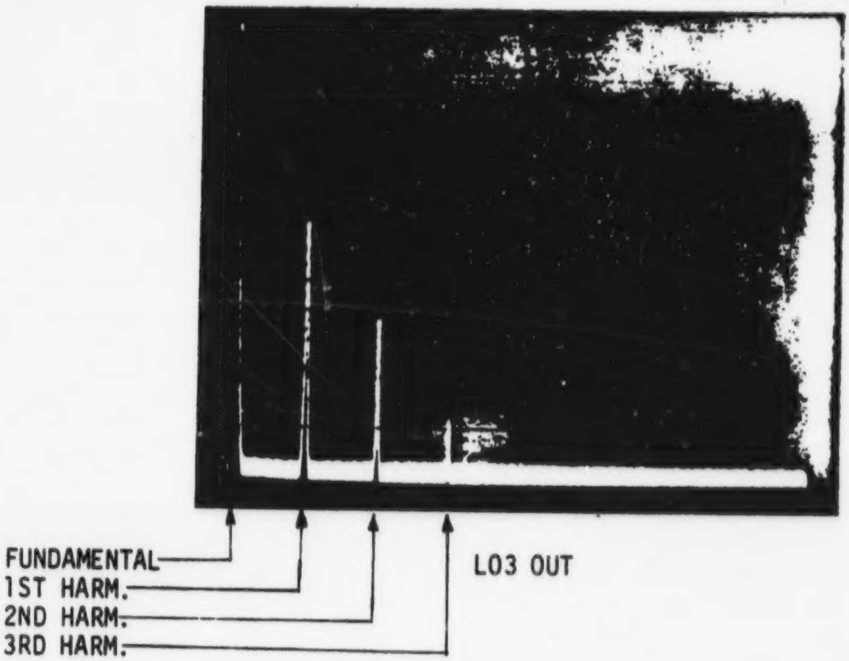
SETTINGS

BW = 30 KHz
SCAN W = 5 MHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

LO3 OUT

TA = 22°C

Figure 27



SETTINGS

BW = 30 KHz
SCAN W = 2 MHz/DIV
VERT = 10 dB/DIV
VIDEO FILTER = None
SCAN TIME = 0.1 SEC/DIV

TA = 22°C

Figure 28

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DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO
DIRECTION FINDER

Progress Report No. 7

For The Period, December 31, 1982

To January 31, 1983

DSS File No. - 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

Distribution

TDC (5)
Science Procurement Manager (1)

By: W. Jones
Project Co-ordinator

BAYLY
ENGINEERING
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1. **Scope**

This is the seventh progress report on the development of the Quasi-Doppler RDF system for Marine purposes, covering the period from December 31, 1982 to January 31, 1983.

2. **Matters Arising from Progress Report No. 6**

Those items stated to be outstanding in Reports #5 and #6 remain as such, relating primarily to contractual matters.

3. **Current Status**

All material and component procurement has been completed to the level considered advisable at this time. No further procurement is being undertaken until such time as matters contained in paragraph 2 above have been clarified and implemented.

Tests have been completed on the frequency sythesizer (report enclosed). This unit met specification on all counts with the exception that the 25 kHz sidebands exceed the permissible limits at certain frequencies. This problem is under current investigation.

Testing of the dipoles has now been completed. The technical report will be included in the next progress report.

4. **Personnel**

There have been no changes in project personnel.

5. **Contractual**

Work is proceeding on the completion of a detailed report covering block J2 of the SPEC Chart.

6. General

With the exception of items discussed above, the remainder of the project is, at the present time, in a hiatus condition awaiting contractual instructions.

W. Jones

W. JONES

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DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

Progress Report No. 8

For The Period January 31, 1983
To February 28, 1983

DSS FILE NO.: 12ST.T8200-1-1515

Bayly Engineering
W.O. 290006

DISTRIBUTION:

TDC (5)
Science Procurement Manager (1)

BY: W. Jones
Project Co-ordinator

BAYLY
ENGINEERING
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1. **Scope**

This is the eighth progress report on the development of the Quasi-Doppler RDF system for Marine purposes, covering the period from January 31, 1983 to February 28, 1983.

2. **Matters Arising from Progress Report No. 7**

Items noted in paragraph 2 of Report No. 7, are still outstanding.

3. **Current Status**

As noted in Report No. 7, paragraph 3, the test report on the antenna dipoles is enclosed. No further work on the antenna is being undertaken at this time.

The frequency synthesizer has been returned to the sub-contractor for corrective action to reduce the 25 kHz sidebands and will be reported on at a later date.

4. **Personnel**

All personnel have been allocated to other projects pending decisions awaited under paragraph 2.

5. **Contractual**

Completion of the expanded report relating to block J2 of the SPEC Chart is being undertaken.

6. **General**

No further development under the terms of the contract is being conducted at this time with the exception of the frequency synthesizer (above).

W. Jones

W. JONES

AEG-TELEFUNKEN

To G. Krajewski

From B^YLY ENGINEERING LIMITED

Name Raymond Labonté

Telephone (514)· 378-4643 Ext. 218

Received/Copies to K. Hore

Your Ref.

Our Ref.

Date Feb. 17/198

[illegible],
Canada '

Subject PROGRESS REPORT ON ATC/MARINE DOPPLER ANTENNA DIPOLES AND ASSOCIATED CIRCUITS

The first part of the report is in relation with our memo dated 04.06.82. Since then a first type of ferrite cores has been ordered and received and new dipole balun transformer made.

It has been found that these cores would be best suitable for HF range, their insertion losses being excessive at VHF. Therefore, cores with the next lower μ value have been ordered, received and eight new transformers made, tested and found to be very good as it can be seen on the test sheets (Fig. 1-8). Winding datas and manufacturer core part # are also included on the sheets.

Then the work on the Marine Doppler Dipole has been started, using the same configuration as for the ATC Doppler. However, the standard length equation, $l = \frac{0.95C}{2(F_1 F_2)^{\frac{1}{2}}}$ has been replaced by $l = \frac{C}{2 F_{(max)}}$ which yields, for this frequency range, an extra length of one inch or so, in case of some shortening effect possibly introduced by the dipole central metallic support or neighbour elements.

At the Planning meeting of Sept. 20th, 1982, the possibility of standardizing the dipole impedance to 50 Ω was advocated, for the obvious reason of test equipment and component availability.

It was also mentioned that it would be desirable to depart from the actual offcenter feed for a symmetrical one. Two breadboard dipoles that would fulfill the above requirements have been made and tested and the impedance curves can be seen on Fig. 9-11 with pertinent details on each graphs.

A new mean for the injection of the Test Signal consisting of a pair of plates, balanced feed and capacitivly coupled to each dipole (K = 3%), in accordance with the alternate Test Injection Scheme outlined by Marcel Lebeau in the TM8212, has also been implemented and the test results can be seen on Fig. 12 while the coupling between two adjacent dipoles is shown on Fig. 13.

/...2

Unfortunately, at the time of the job closure, there was no proper drawing made; therefore only rough sketches or notes are existing and some components are not the final ones since for the breadboard construction we had to use components that we had on hand.

Also, the curves shown on Fig. 14 and 15 have been recorded with the transformer on the bench. They have been optimized since then when fitted into the dipoles; the only remaining capacitor is a 6 pF at the Input Jack. Others being removed to the benefit of Impregnation and Neon Capacitance.

Raymond Labonte

Raymond Labonté

/sgv
Att.

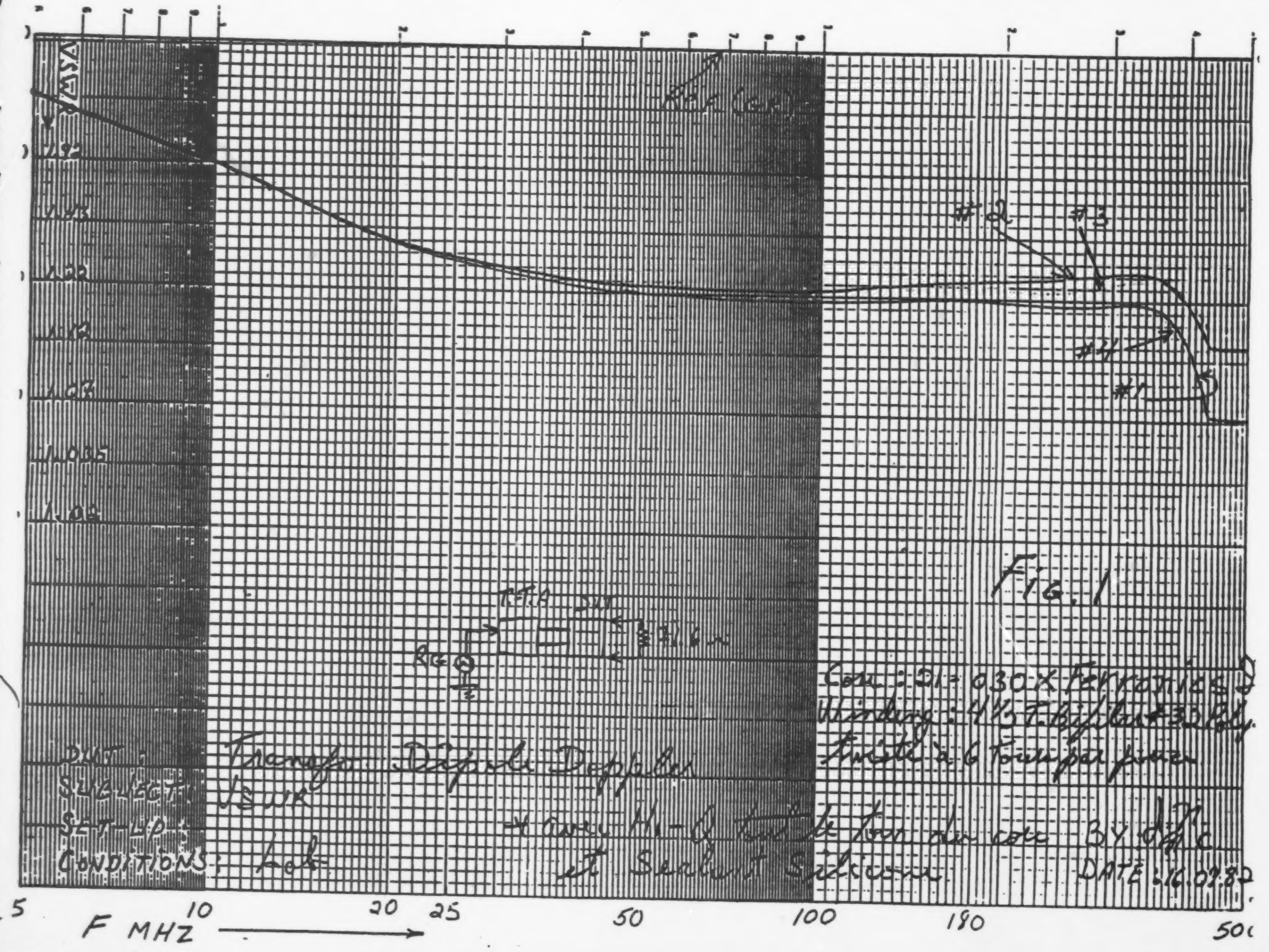


FIG. 1

Core : D1 - 030 X Ferronics
Winding : 4½ T. bifilar #30 Poly.
twisté à 6 tours par pouce

DUT : Transfo Dipole Doppler
SUBJECT : VSWR
SET-UP :
CONDITIONS : Lab

+ avec Hi-Q tuté le tour du core
et Scellé Silicone

BY: JJC
DATE: 16.07.82

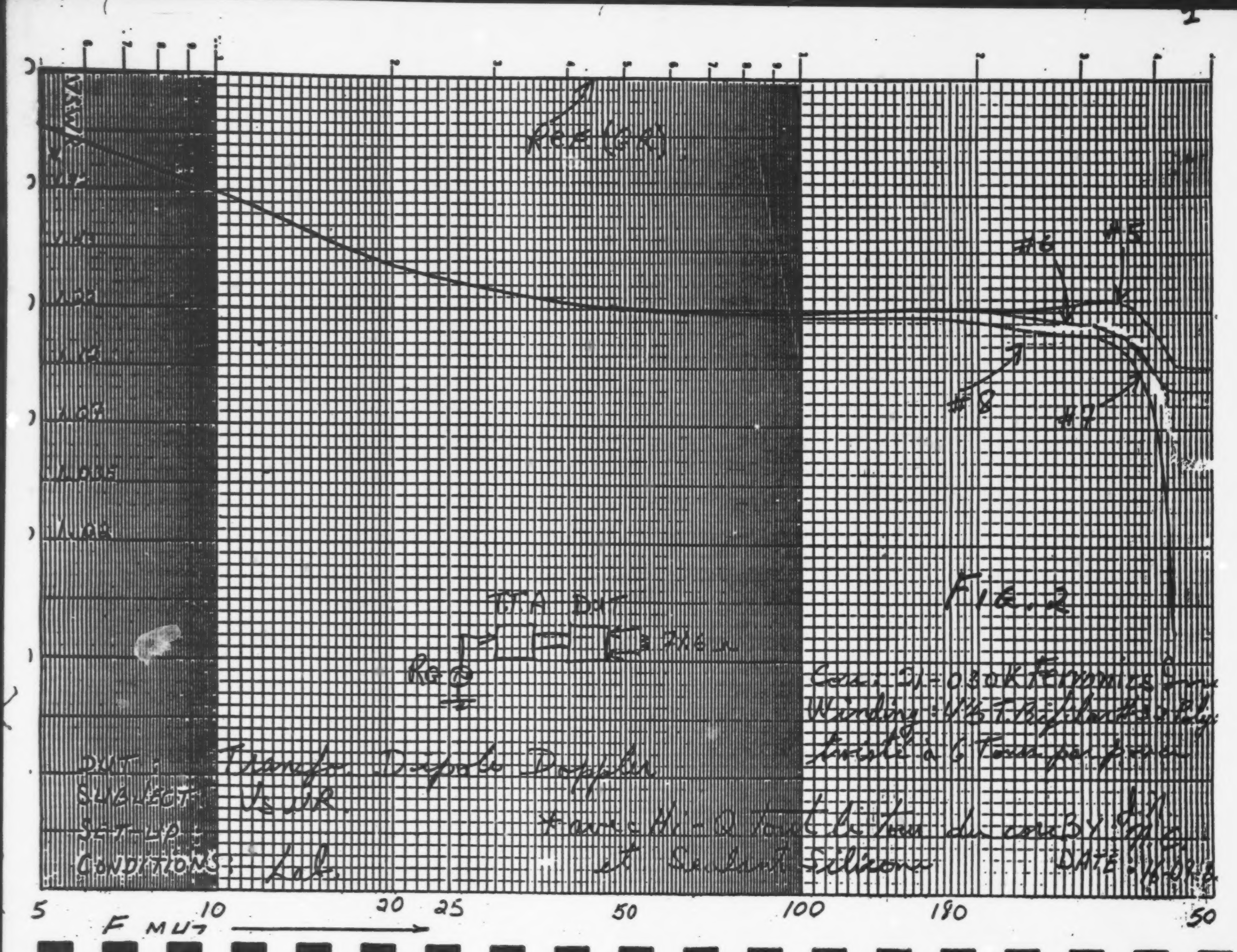


FIG. 2

Core: D1-030K Ferronics [illegible]
Winding: 4½ T. trifilar [illegible]
twisté à 6 Tours par pouce

DUT: Transfo. Dipole Doppler
SUBJECT: V.S.W.R.
SET-UP:
CONDITIONS: Lab.

* avec Hi-Q tout le tour du core
et [illegible] Silicone

BY: [illegible]
DATE: [illegible]

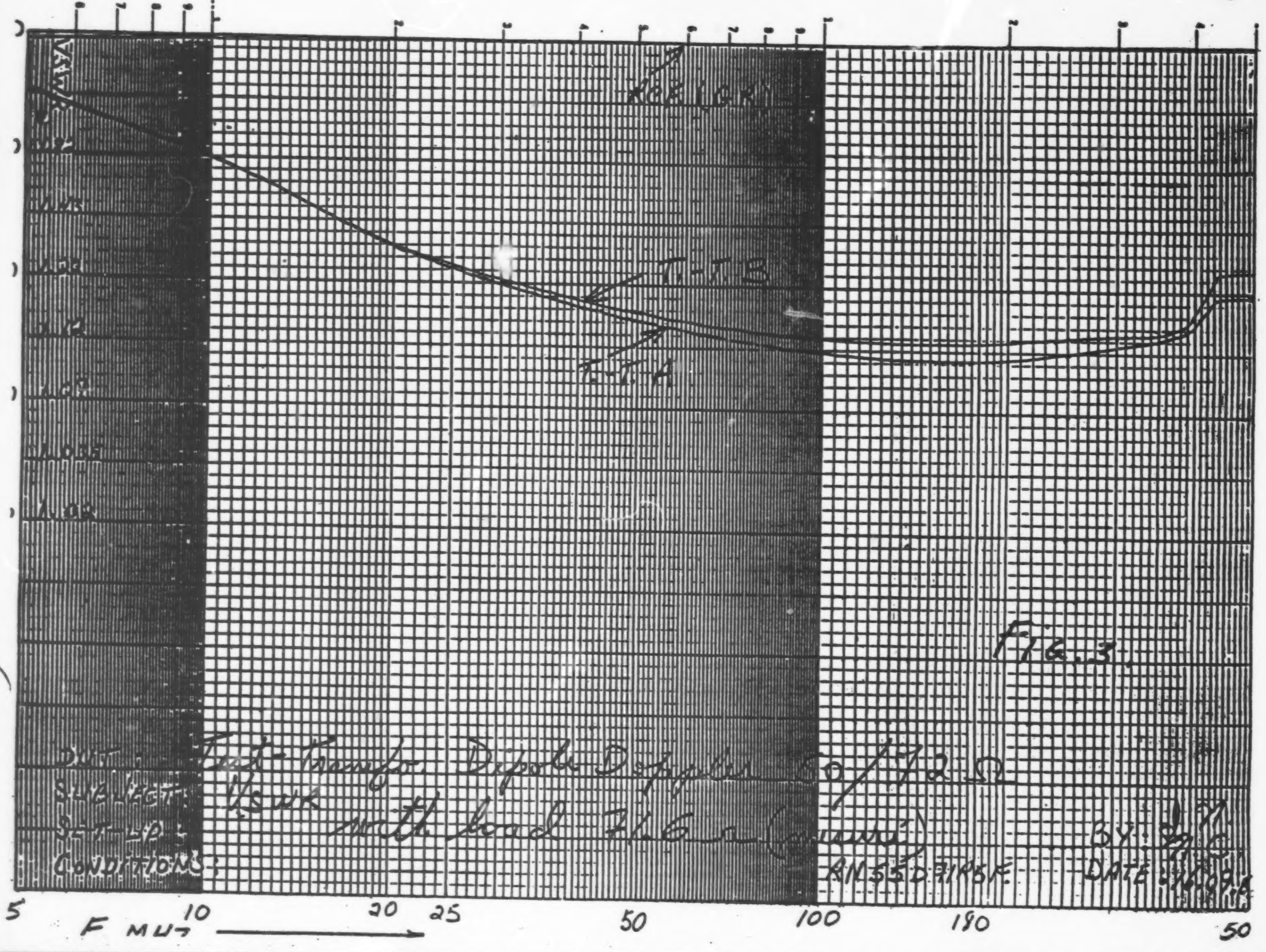

VSWR
REF LGR
T-T B
T-T A
DUT: Test-transfo Dipole Doppler 50/72 Ω
SUBJECT: VSWR
SET-UP: with load 72.6 Ω (quarri)
CONDITIONS:
AN55D71R5F
BY:
DATE:
5
10
20
25
50
100
180
50
F MHz

FIG. 3.

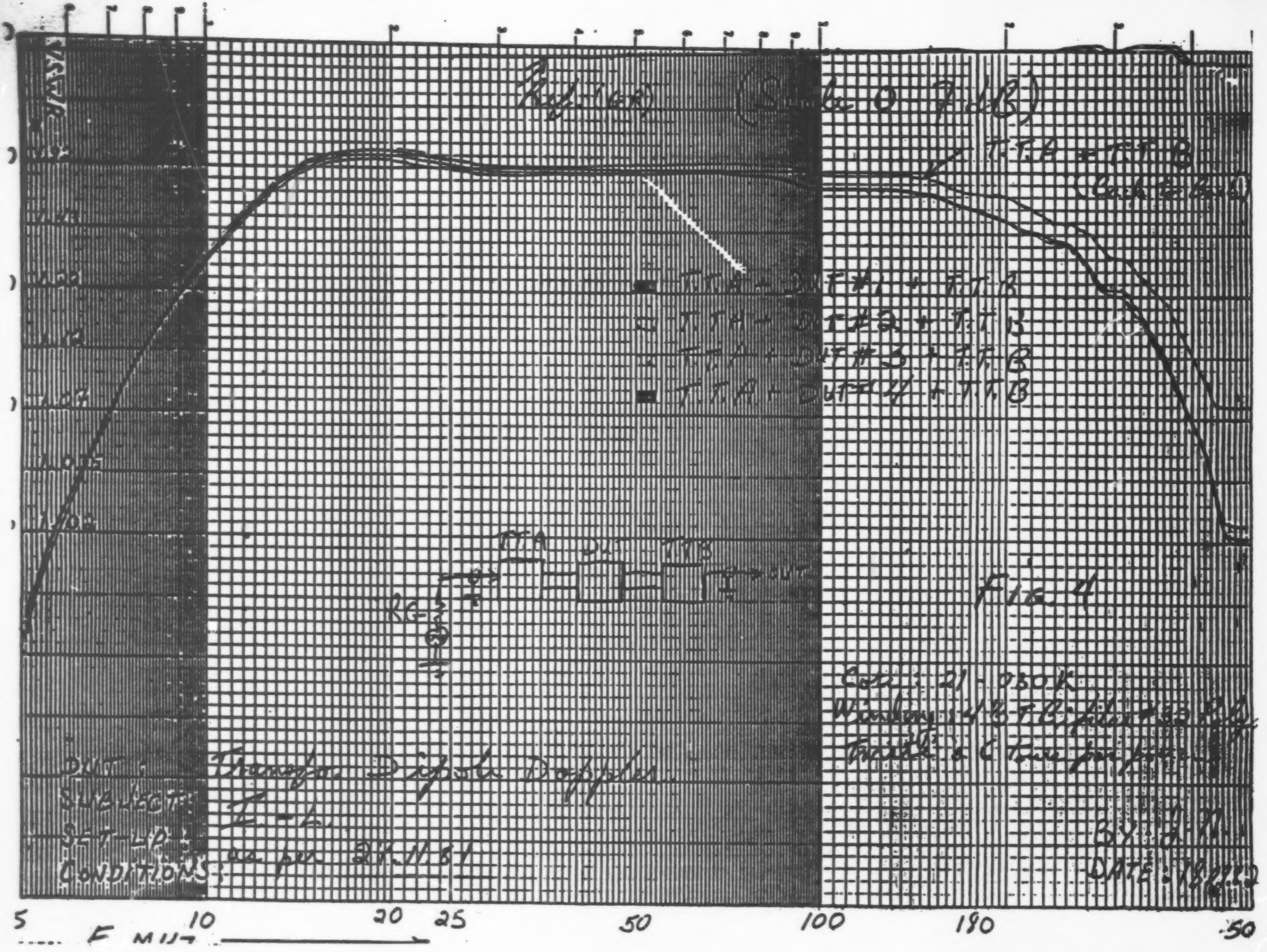


Fig. 4

Cat: 21-050K
Winding 1-4 & 7-8 bifilar #30 P.E.
Twisted 6 C turns per foot

BY: J. M.
DATE: 18.2.62

DUT: Transfo. Dipole Doppler
SUBJECT: Z - L
SET-UP: }
CONDITIONS: } as per 2K.11.61

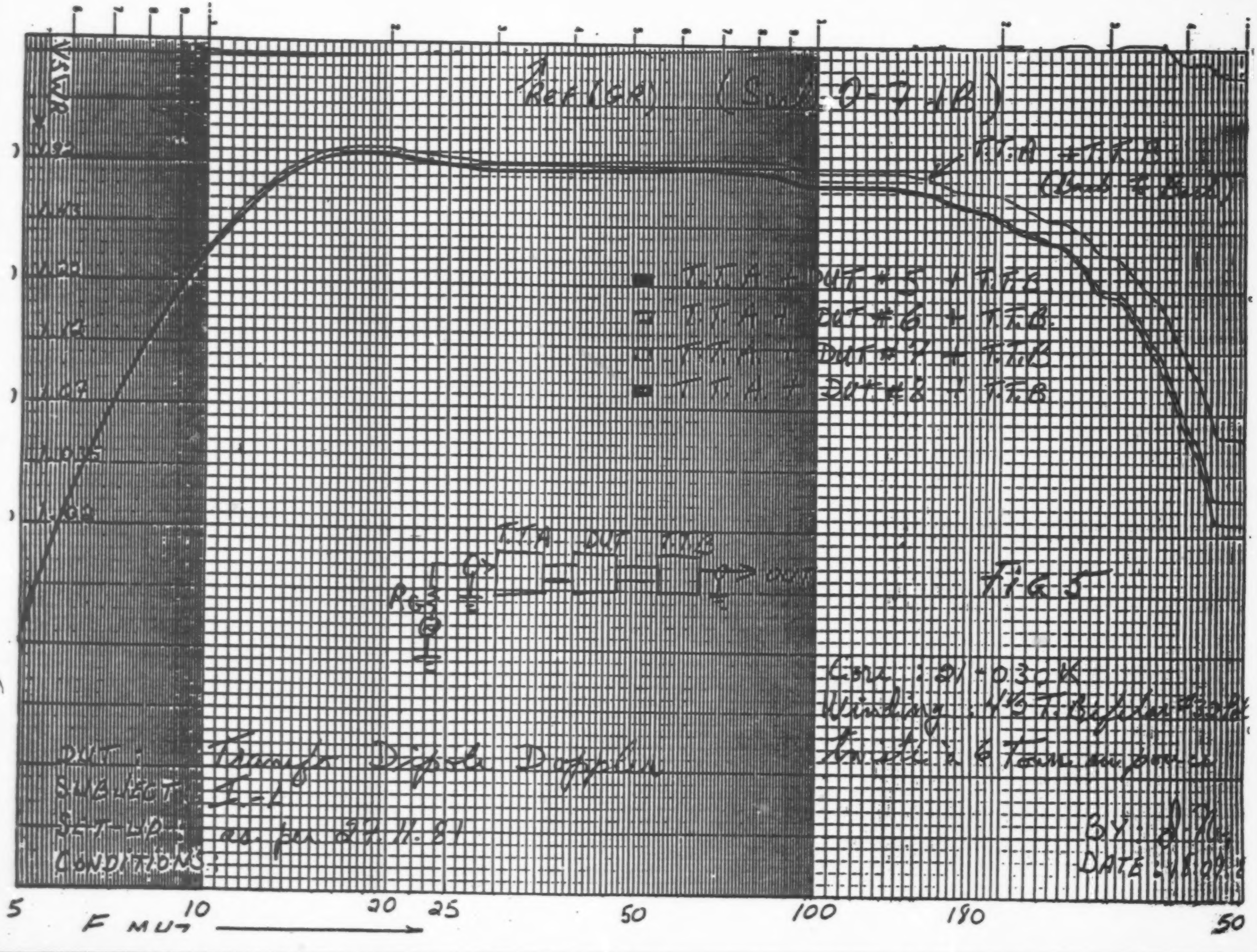


FIG 5

DUT : Transf. Dipole Doppler
SUBJECT : I-1
SET-UP : as per 27.11.87
CONDITIONS :

Core : 21-030K
Winding : 4 T. Bifilar #32
torsadé à 6 tours au pouce

BY : J.M.
DATE : 18.09.

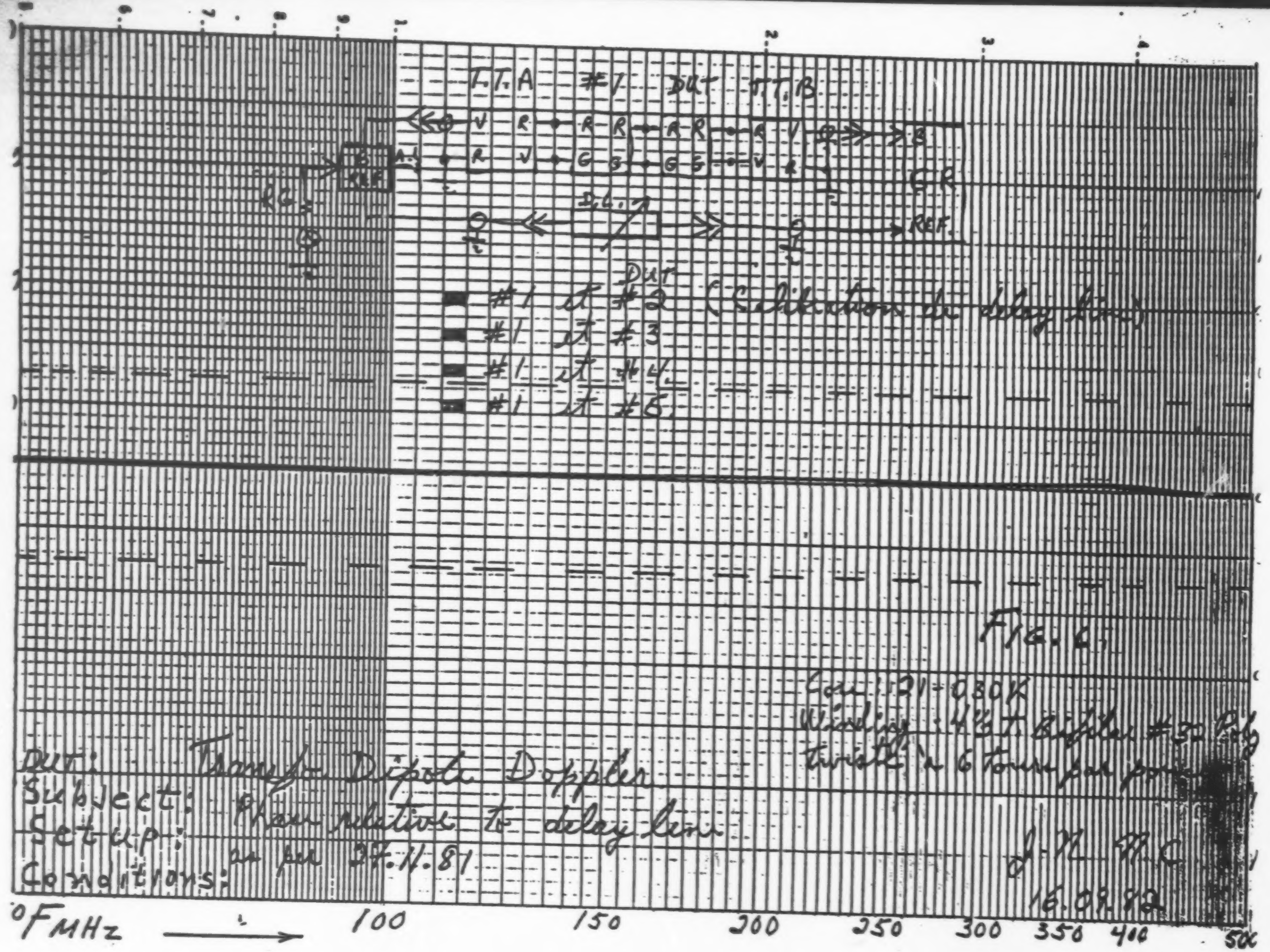


Fig. 6

Core: 21-030K
Winding: 4½ T. bifilar #30 AWG
twisted à 6 tours par pouce

J. M. M. C
16.09.92

DUT: Transf. Dipole Doppler
Subject: Phase relative to delay line
Set up: as per 27.11.81
Conditions:

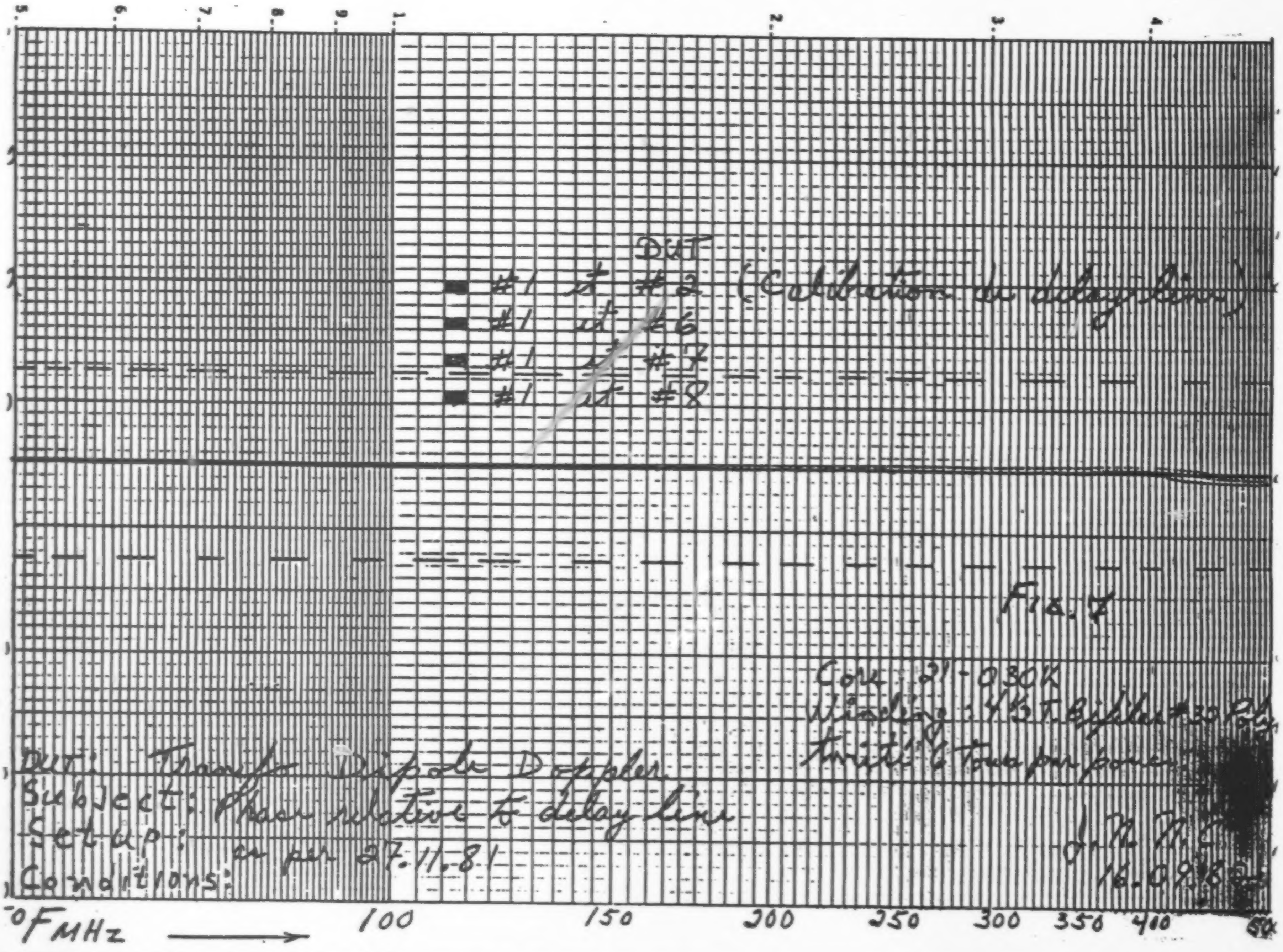
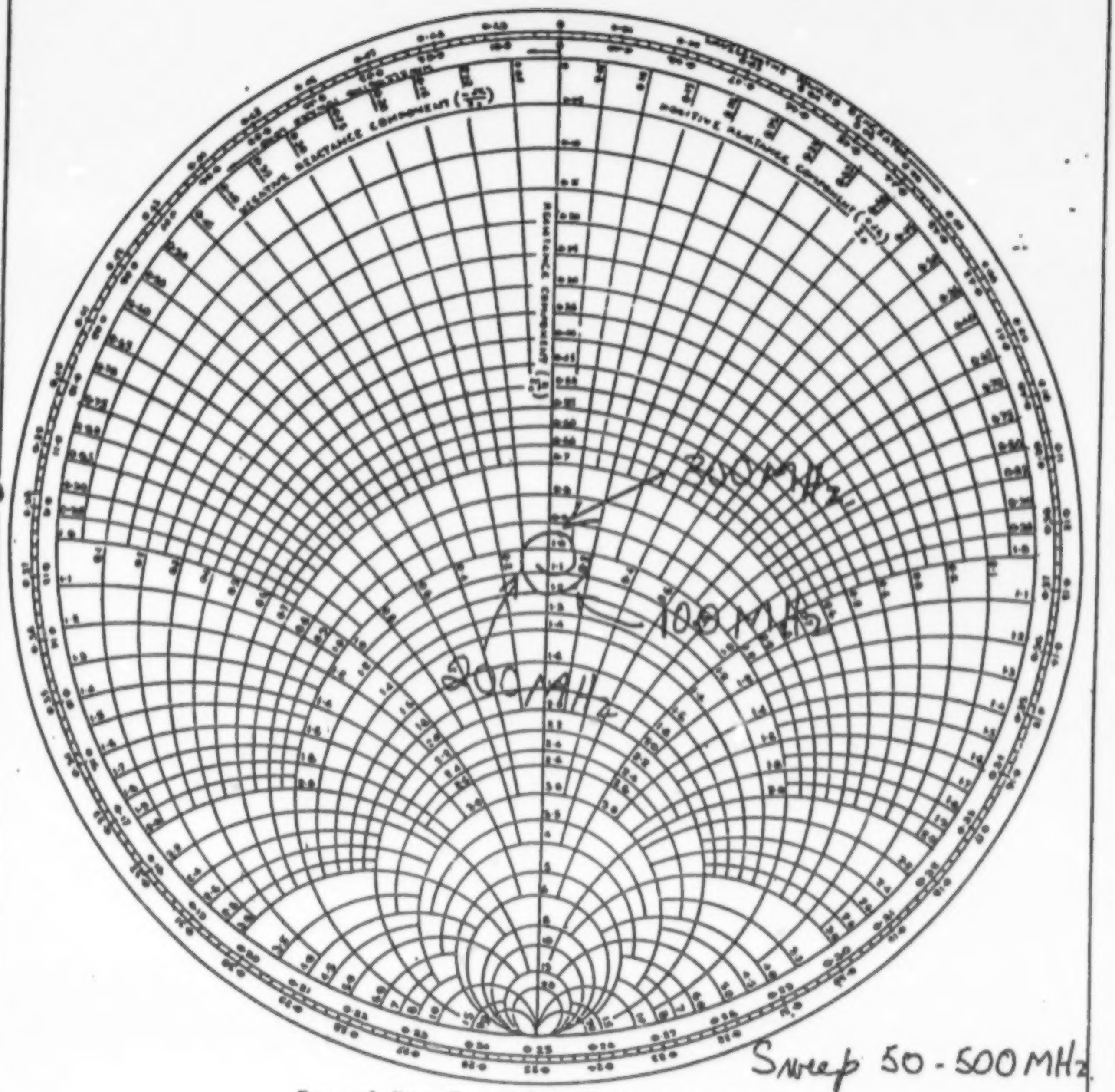


Fig. 7

DUT: Transfo Dipole Doppler
Subject: Phase relative to delay line
Set up: as per 27.11.81
Conditions:

Core: 21-030K
Winding: 4½T bifilar #30 [illegible]
twisted 6 Turns per pouce

J. M. R.
16.09.82



Sweep 50-500MHz

Fig. 10.16. Polar Form of Circle Diagram of Impedance

436

Fig. 8.

DUT: Transfo. Dipole Doppler #8

Set-up: VSWR

Conditions: T.T.A + DUT #8 + 71.6 Ω

Core: 21-030K

CORPORATION d'ELECTRONIQUE SHEFFORD
SHEFFORD ELECTRONICS CORPORATION

[illegible]

SIGNATURE			
D	M	Y	

SEC. J-N. M.C
REF.
No. 22.09.82
SHEET

①

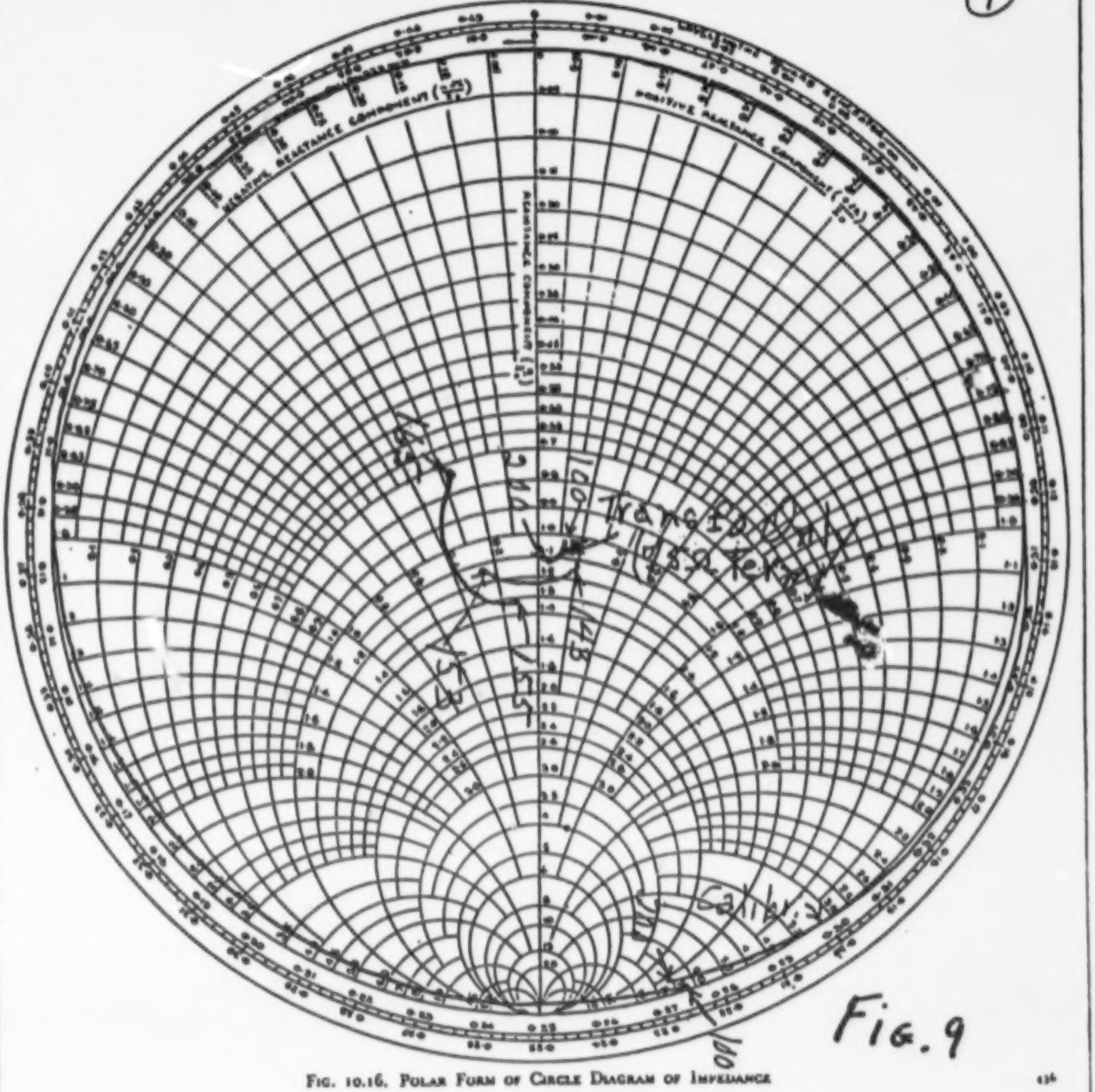


Fig. 9

FIG. 10.16. POLAR FORM OF CIRCLE DIAGRAM OF IMPEDANCE

136

DUT: Marine Doppler Dipole; $l = \frac{\lambda\, min}{2} = 0.915$ m. (36.0")

Set-up: 75Ω, Bal. : 50Ω Unbal. built-in.

Conditions: Dipole alone (no casting or neighbour)

08.11.92 R.L.+G.D.

SEC

CORPORATION d'ELECTRONIQUE SHEFFORD
SHEFFORD ELECTRONICS CORPORATION

SIGNATURE		
	SEC.	
	REF.	
	NO.	
D | M | Y	SHEET	OF

②

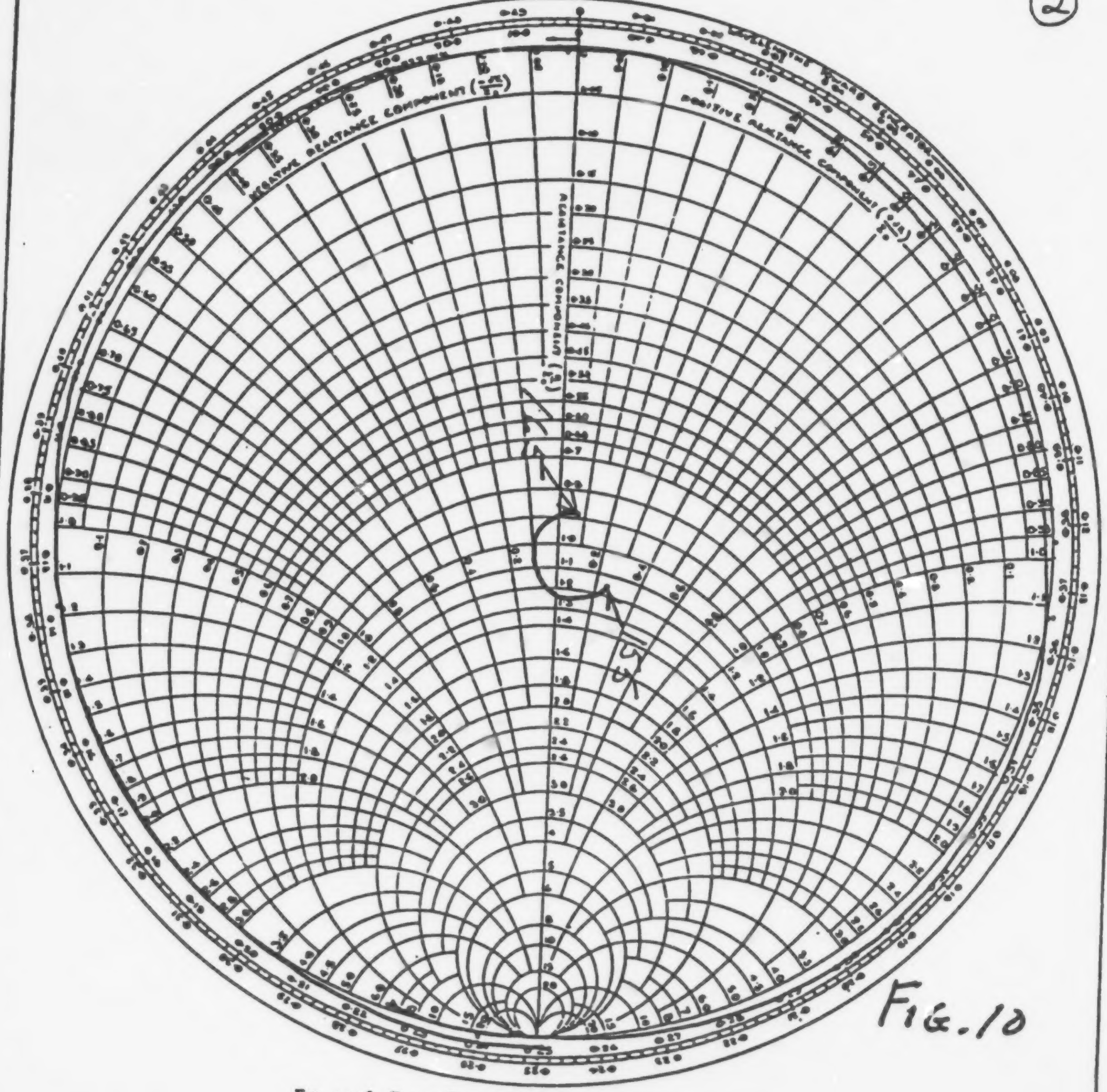


FIG. 10

FIG. 10.16. POLAR FORM OF CIRCLE DIAGRAM OF IMPEDANCE

DUT: Marine Doppler Dipole

Set-up: } "Same as ① except + Casting +

Conditions: } Counterpoise; no neighbour;

DUT Hor. ≈ 54" above floor.

09. 11. 82. R.L. + G.D.

CORPORATION d'ELECTRONIQUE SHEFFORD
SHEFFORD ELECTRONICS CORPORATION

SIGNATURE	SEC.
	REF.
	No.
D | M | Y	SHEET OF

11

(3)

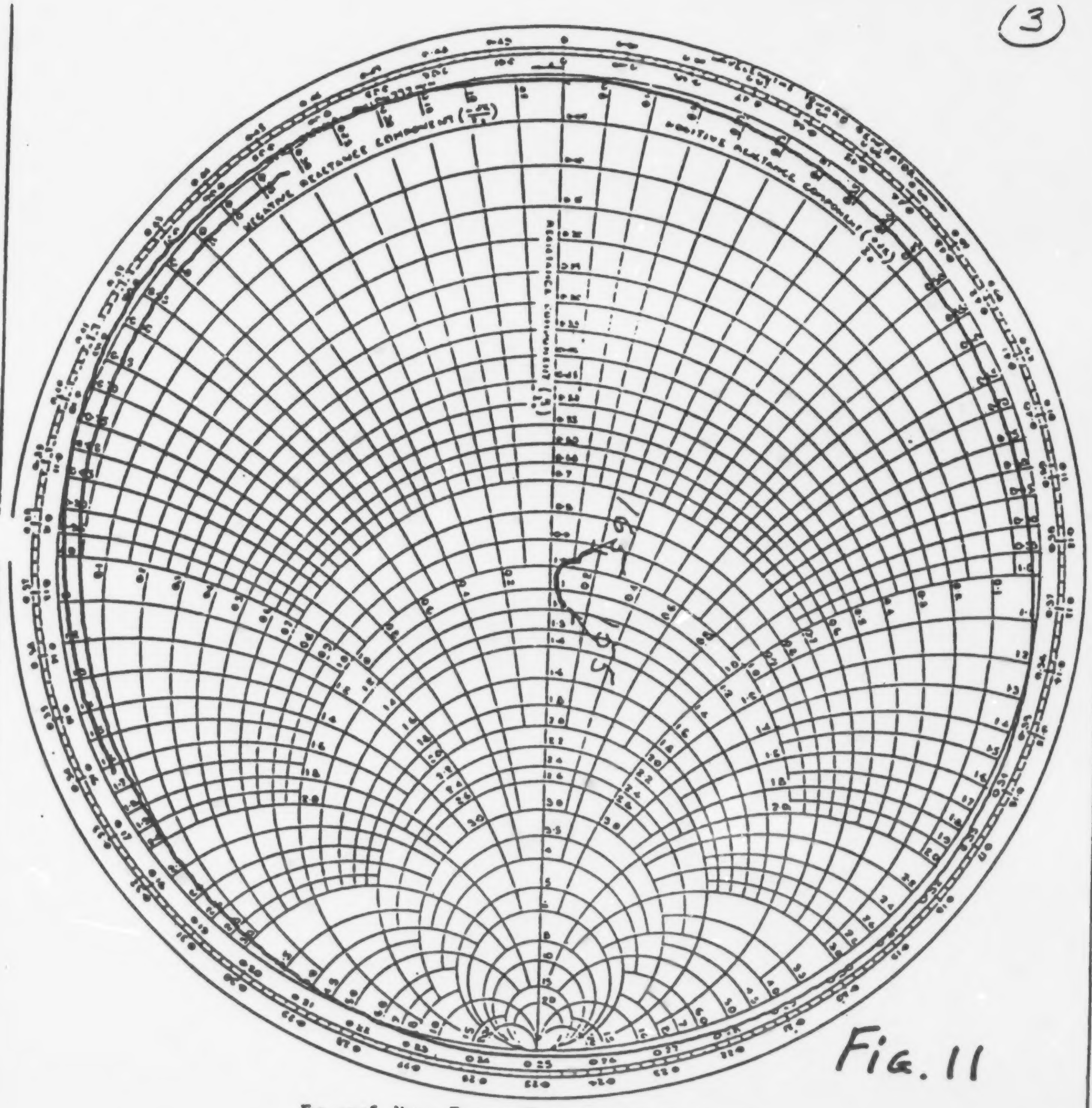


Fig. 11

Fig. 10.16. Polar Form of Circle Diagram of Impedance

DUT: Marine Doppler Dipole

Set-up: } Same as ① except + 1 neighbour,
Conditions: } spaced by 24."

DUT. Hor. ≃ 54" above floor.

10.11.82. RLt G.D.

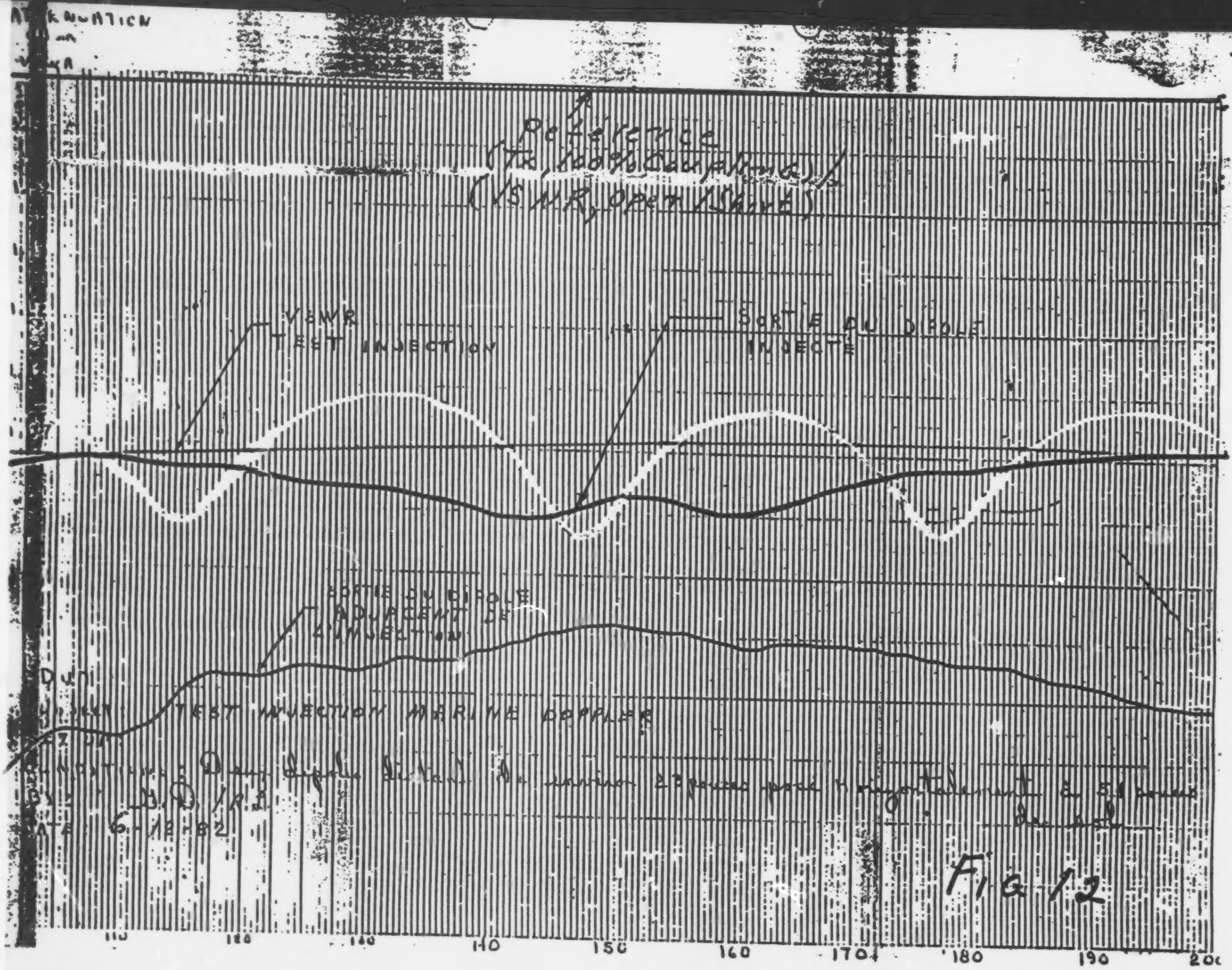

ATTENUATION
VSWR
Reference
(Tx, 100% Coupling) /
(VSWR, Open / Short)
VSWR
TEST INJECTION
SORTIE DU DIPOLE
INJECTE
SORTIE DU DIPOLE
ADJACENT DE
L'INJECTION
DUT
TEST INJECTION MARINE DOPPLER
ANNOTATIONS: [illegible] dipole [illegible] 2 [illegible] horizontalement [illegible] 5 [illegible]
BY: B.D. / R.S.
DATE: 6-12-82
110
120
130
140
150
160
170
180
190
200

FIG 12

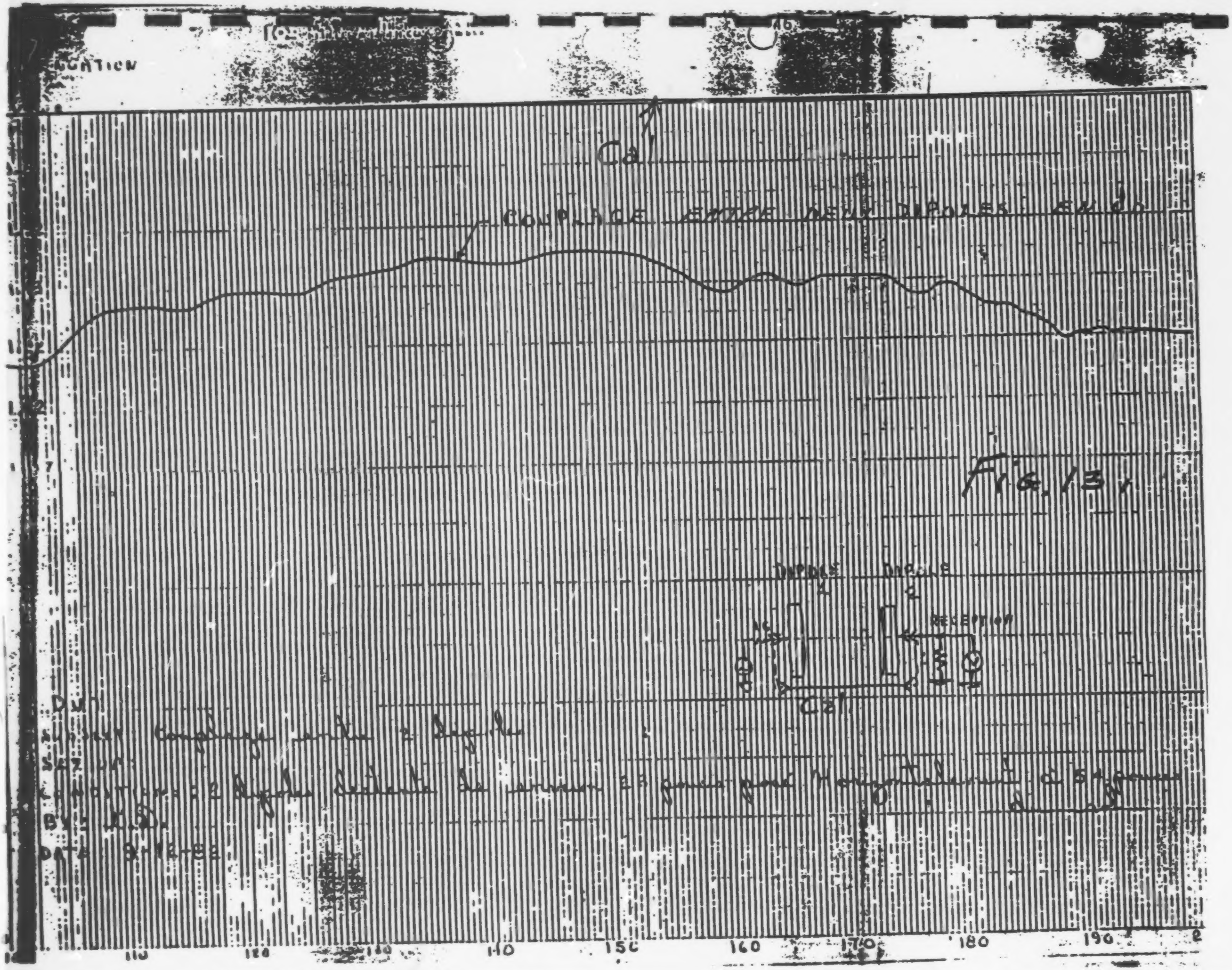


Fig. 13 r

LOCATION
Cal
COUPLAGE ENTRE DEUX DIPOLES EN dB
DIPOLE 1
DIPOLE 2
RECEPTION
Cal
DUT
SUBJECT couplage entre 2 dipôles
SET UP
CONDITIONS: 2 dipôles
BY:
DATE 8-12-82
110
120
130
140
150
160
170
180
190

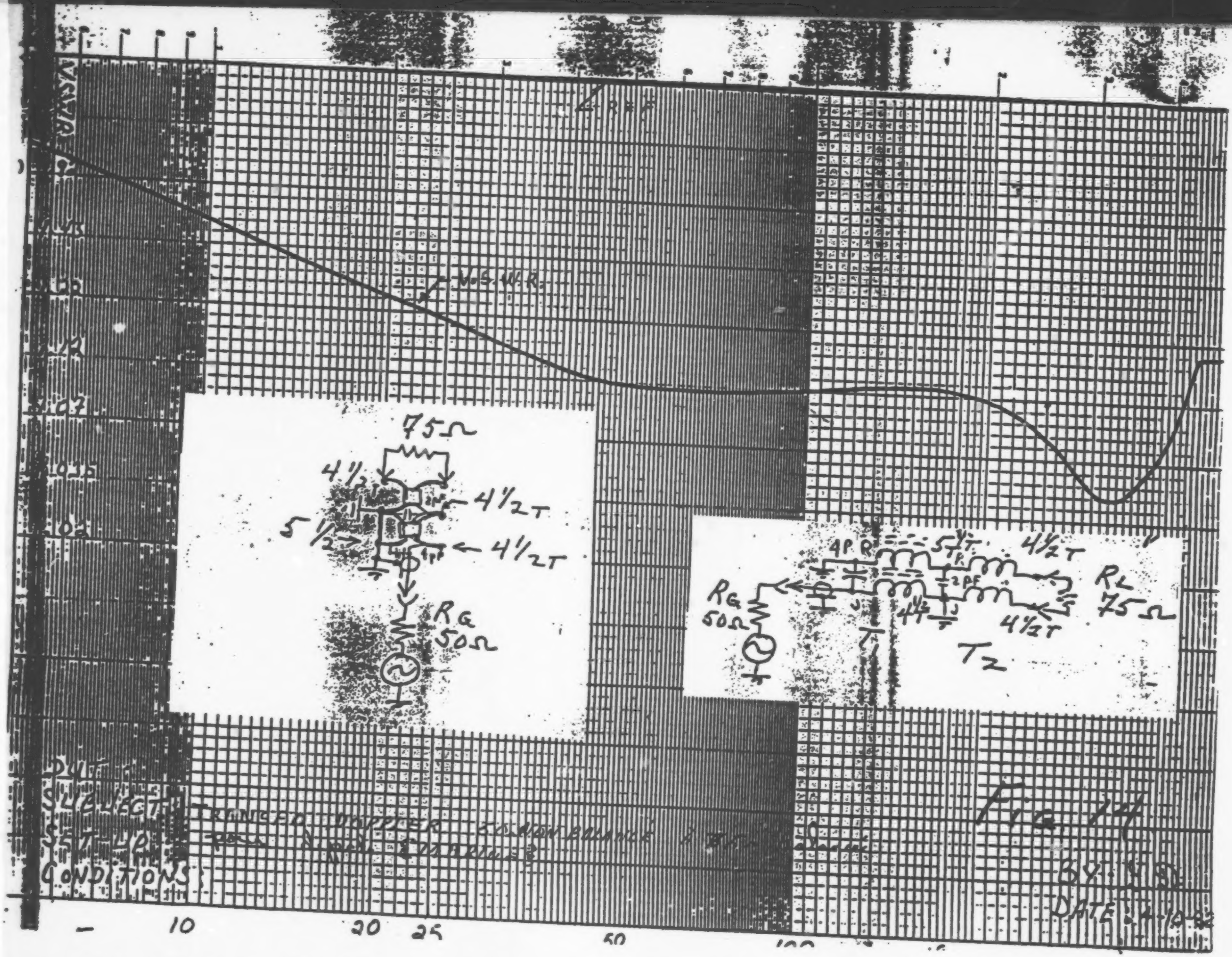


Fig. 14

BY: [illegible]

DATE: [illegible]

15

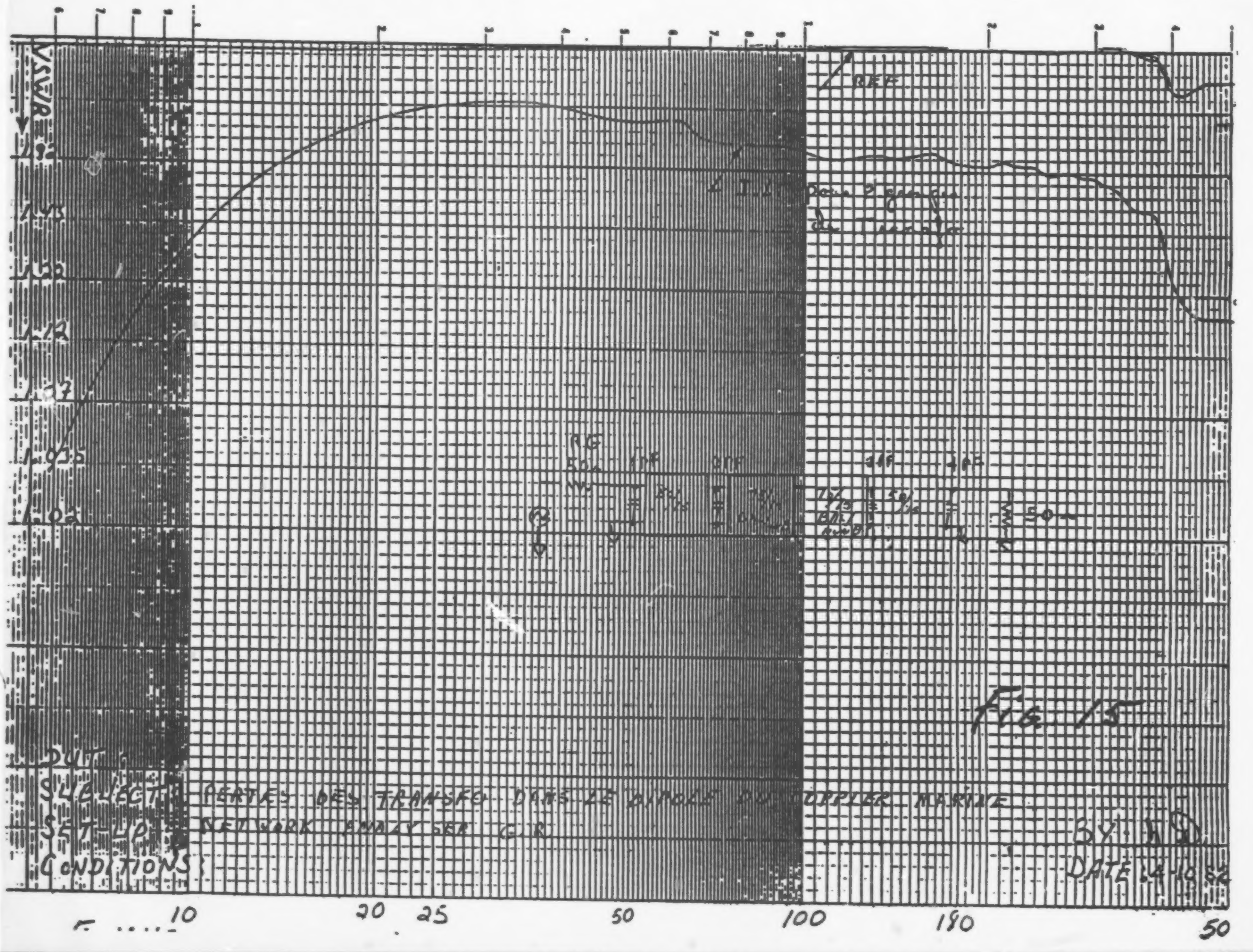


FIG. 15

DUT:
SUBJECT: PERTES DES TRANSFO DANS LE DIPOLE DU CORPLER MARINE
SET-UP: NETWORK ANALYSER G.R.
CONDITIONS:

BY: [illegible]
DATE: 4-10-82

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DEVELOPMENT AND DESIGN OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO DIRECTION FINDER

PROGRESS REPORT NO. 9

FOR THE PERIOD FEBRUARY 28, 1983 - MARCH 31, 1983

DSS File No. 12ST.T8200-1-1515

Bayly Engineering Ltd.
W.O. 290006

Prepared by:

W. Jones
Project Co-ordinator

Distribution:

TDC (5)
Science Procurement Manager (1)

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1. SCOPE

This is the ninth progress report on the development of the Quasi-Doppler RDF system for Marine purposes, covering the period from February 28, 1983 to March 31, 1983.

2. MATTERS ARISING FROM PROGRESS REPORT NO. 8

Items outstanding in past reports as covered in paragraph 2 of Report No. 8 are still outstanding.

3. CURRENT STATUS

With the exception of the frequency synthesizer returned to subcontractor as recorded in Report No. 8, no further work has been carried out on this contract.

4. PERSONNEL

As recorded in Report No. 8

5. CONTRACTUAL

The completion of the expanded report (Block J2 Spec.) is on hold pending finalization of the ATC report.

6. GENERAL

The contract is in abeyance at this time awaiting government decisions.

DEVELOPMENT AND DESIGN
OF A PROTOTYPE QUASI-DOPPLER MARINE RADIO
DIRECTION FINDER

Progress Report #10

For The Period April 1 to April 30, 1983

DSS File No. - 12ST.T8200-1-1515

Bayly Engineering Ltd.
W.O. 290006

Distribution:

TDC (5)
Science Procurement Manager (1)

Prepared By:
W. Jones
Project Co-ordinator

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1. SCOPE

This is the tenth progress report on the development of the Quasi-Doppler RDF system for Marine purposes, covering the period from April 1 to April 30, 1983.

2. MATTERS ARISING FROM PROGRESS REPORT #9

As per item 2, Report #9.

3. CURRENT STATUS

With inventory taking completed, no further work has been carried out on this contract.

4. PERSONNEL

As recorded in Report #8.

5. CONTRACTUAL

As per item 5, Report #9.

6. GENERAL

The contract is now in complete abeyance awaiting government instruction.

W. Jones

W. JONES

POOR

QUALITY

ORIGINAL